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ТОМСКИЙ ПОЛИТЕХНИЧЕСКИЙ УНИВЕРСИТЕТ»**

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МАГИСТЕРСКАЯ ДИССЕРТАЦИЯ

Тема работы
Анализ эффективности эксплуатации парогенераторов АЭС

УДК 681.181.004:621.311.25

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Томск - 2018

Ministry of Education and Science of the Russian Federation
Federal Independent Educational Institution
"NATIONAL RESEARCH TOMSK POLYTECHNIC UNIVERSITY"

School: School of Nuclear Science & Engineering
Direction of training (Specialty): Nuclear Physics and Technology
Division: Nuclear fuel cycle

MASTER'S THESIS

Topic of the work
The performance of modern steam generator at nuclear power plants

UDC 681.181.004:621.311.25

Student

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Senior lecturer	Verigin D.A	PhD		

ADMIT TO DEFENSE:

Position	**Full name**	**Academic degree, academic rank**	**Signature**	**Date**
Nuclear power installations operation	Verchoturova V.V	PhD		

Tomsk – 2018

Expected learning outcomes

Result code	The result of the training (the graduate should be ready)	Requirements of the FSES HE, criteria and / or stakeholders
	professional competencies	
LO1	To apply deep mathematical, natural scientific, socio-economic and professional knowledge for theoretical and experimental research in the field of the use of nuclear science and technology	FSES HE Requirements (PC-1,2, 3, 6, UC-1,3), Criterion 5 RAEE (p 1.1)
LO2	Ability to define, formulate and solve interdisciplinary engineering tasks in the nuclear field using professional knowledge and modern research methods	FSES HE Requirements (PC-2,6,9,10,14 UC-2,3,4, BPC1,2), Criterion 5 RAEE (p 1.2)
LO3	Be able to plan and conduct analytical, simulation and experimental studies in complex and uncertain conditions using modern technologies, and also critically evaluate the results	FSES HE Requirements (PC-4,5,6,9,22 UC-1,2,5,6), Criterion 5 RAEE (p 1.3)
LO4	To use the basic and special approaches, skills and methods for identification, analysis and solution of technical problems in nuclear science and technology	FSES HE Requirements (PC-7,10,11,12,13 UC-1-3,BPC1,3), Criterion 5 RAEE (p 1.4)
LO5	Readiness for the operation of modern physical equipment and instruments, to the mastery of technological processes during the preparation of the production of new materials, instruments, installations and systems	FSES HE Requirements (PC-8,11,14,15, BPC-1), Criterion 5 RAEE (p 1.3)
LO6	The ability to develop multivariate schemes for achieving the set production goals, with the effective use of available technical means	FSES HE Requirements (PC-12,13,14,16, BPC-2), Criterion 5 RAEE (p 1.3)
	cultural competencies	
LO7	The ability to use the creative approach to develop new ideas and methods for designing nuclear facilities, as well as modernize and improve the applied technologies of nuclear production	FSES HE Requirements (PC-2,6,9,10,14, UC-1,2,3), Criterion 5 RAEE (p 1.2,2.4,2.5)
	basic professional competencies	
LO8	Independently to study and continuously to raise qualification during all period of professional work.	FSES HE Requirements (PC-16,17,21, UC-5,6, BPC-1), Criterion 5 RAEE (p 2.6) coordi- nated with the requirements of the international standard EURACE & FEANI

LO9	Actively own a foreign language at a level that allows you to work in a foreign language environment, develop documentation, present results of professional activity.	FSES HE Requirements (BPC-3, UC-2,4), Criterion 5 RAEE (p 2.2)
LO10	To demonstrate independent thinking, to function effectively in command-oriented tasks and to have a high level of productivity in the professional (sectoral), ethical and social environments, and also to lead the team, form assignments, assign responsibilities and bear responsibility for the results of work	FSES HE Requirements (PC-18,20,21,22,23 UC-1,4, BPC-2), Criterion 5 RAEE (p 1.6,2.3) coordinated with the requirements of the international standard EUR-ACE & FEANI

Ministry of Education and Science of the Russian Federation

Federal Independent Educational Institution

"NATIONAL RESEARCH TOMSK POLYTECHNIC UNIVERSITY"

School: School of Nuclear Science & Engineering

Direction of training (Specialty): Nuclear Physics and Technology

Division: Nuclear Fuel Cycle

APPROVED BY:
Programme Director
________________Verchoturova V.V
(Signature) (Date)

ASSIGNMENT

for the Master's Thesis completion

Master's Thesis

For a student:

Group	Full name
0АМ6И	Ansah Michael Nii Sanka

Topic of the work:

The performance of modern steam generators at nuclear power plants	
Approved by the order of the Head (date, number)	№1882/c at 19.03.2018

Deadline for completion of the Master's Thesis:	04.06.2018

TERMS OF REFERENCE:

Initial data for work	- Technical data of the WWER-1200 steam generator; - Literature sources; - Test results of moisture separation - Design of louvre separators documentation

List of the issues to be investigated, designed and developed	- A literature review on the operation of steam generators of nuclear power plants was documented considering their advantages and disadvantages of designs of steam generators. - Analysis of ways to address the negative effects in the steam generators. - Comparative analysis of steam generating path in the WWER units. - The identification of promising designs of steam generators for two-circuit nuclear power plants.
List of graphic material	N/A
Advisors on the sections of the Master's Thesis	
Chapter	**Advisor**
One: Literature Review	Bespalov V. I.

Two: Methodology	Bespalov V. I.
Three: Results	Bespalov V. I.
Four: Financial management, resource efficiency and conservation	Timur R. R.
Five: Social Responsibilities	Verigin D. A.

Date of issuance of the assignment for Master's Disertation completion according to a line schedule	04.06.2018

The task was issued by the Head:

Position	Full name	Academic degree, academic status	Signature	Date
Professor of the Butakov Research Center	Bespalov Vladimir Ilyich	PhD		

The assignment was accepted for execution by the student:

Group	Full name	Signature	Date
0АМ6И	Ansah Michael Nii Sanka		

ASSIGNMENT FOR THE SECTION "FINANCIAL MANAGEMENT, RESOURCE EFFICIENCY AND RESOURCE SAVING"

Student:

Group	Name
0АМ6И	Ansah Michael Nii Sanka

School	Nuclear Science and Engineering	**Division**	Nuclear Fuel Cycle
Education Level	Master	**Direction / specialty**	Nuclear Physics and Technology

References for "Financial management, resource efficiency and resource conservation":	
1. The cost of research: Logistics, energy, financial, information and human	*According to manual provided*
2. Norms and standards resource consumption	*According to manual provided*
3. used the tax system, tax rates, deductions, discounting and credit	*According to manual provided*
The list of questions for study, design and development:	
1. Evaluation of commercial and innovative potential STI	1. Potential consumers of research results 2. Analysis of competitive technical solutions from the perspective of resource efficiency and resource savings 3. SWOT-analysis **Perform** • Evaluation of the project readiness for commercialization • Methods for the commercialization of scientific and technological research
2. Development of the charter of scientific and technical project	• Objectives and outcomes of the project. • The organizational structure of the project. • Identification of possible alternatives
3. Project management planning: the structure and schedule of the budget, risk and procurement organization	• The structure of the work within the framework of scientific research • Determination of the complexity of work • Scheduling scientific research • The budget of the scientific and technical research (STR)
4. Defining resource, financial, economic efficiency	• Integral financial efficiency indicator • Integral resource-efficiency indicator • Integral total efficiency indicator • Comparative project efficiency indicator
List of graphic material	
1. *Segmentation of the market* 2. *Estimation of competitiveness of technical solutions* 3. *SWOT Matrix* 4. *Schedule and budget of the project* 5. *Assessment resource, financial and economic efficiency of the project*	

Date of issue of assignment	

Assignment given by consultant:

Position	Name	degree	Signature	Date
Associate Professor	Timur R. Rakhimov	PhD		

Assignment received by student for implementation:

Group	Name	Signature	Date
0АМ6И	Ansah Michael Nii Sanka		

ASSIGNMENT FOR THE SECTION "SOCIAL RESPONSIBILITY"

For student

Group	Full name
0AM6И	Ansah Michael Nii Sanka

School	School of Nuclear Science and Engineering	**Division**	Nuclear Fuel Cycle
Degree	Master	**Direction / specialty**	Nuclear Physics and Technology

Input data to the "social responsibility":	
1. *Describe workplace (work area) for occurrence of:*	– Harmful factors of the environment (microclimate, illumination, noise, vibration, electromagnetic fields); – dangerous factors of environment factors (electrical, fire and explosive nature).
2. *Acquaintance and selection of legislative and normative documents on the topic*	– electrical safety; – fire and explosion safety; – labor protection requirements when working on a PC.
The list of subjects to study, design and develop:	
1. *Analysis of the identified harmful factors of the environment in the following sequence:*	– The effect of the factor on the human body; – Reduction of permissible standards with the required dimensionality (with reference to the relevant normative and technical document); – Proposed remedies (collective and individual).
2. *Analysis of identified hazards of the environment:*	– Electrical safety (including static electricity, protective equipment); – fire and explosion safety (causes, preventive measures, primary fire extinguishing agents).

Date of issue of the task for the section according to the schedule	

Task issued by consultant:

Position	Full name	Scientific degree, rank	Signature	date
Senior lecturer	Verigin D. A.	PhD		

The task was accepted by the student:

Group	Full name	Signature	date
0AM6И	Ansah Michael Nii Sanka		

Ministry of Education and Science of the Russian Federation

Federal Independent Educational Institution

“NATIONAL RESEARCH TOMSK POLYTECHNIC UNIVERSITY”

School: School of Nuclear Science and Engineering

Direction of training (Specialty): Nuclear Physics and Technology

Level of education: Master’s Degree

Division of Nuclear Fuel Cycle

Period of completion (fall/spring semester 2017/2018)

Form of presenting the work:

The performance of modern steam generators at nuclear power plants

(Master’s Dissertation)

SCHEDULED COURSE ASSESSMENT CALENDAR

for the Master’s Dissertation completion

Deadline for completion of Master’s Thesis:	04.06.2018

Assessment date	Title of section (module) / type of work (research)	Maximum score of the section (module)
19.03.18	Literature Review and Methodology	
26.03.18	Conducting experiments	
10.04.18	Execution of calculations and analysis of data	
20.04.18	Synthesis and evaluation of results	
07.05.18	Financial management and Social Responsibility	
02.06.18	Writing the dissertation full report	

Made by:

Position	Full name	Academic degree, academic status	Signature	Date
Professor of the Butakov Research Center	Bespalov V. I.	PhD		

AGREED:

Position	Full name	Academic degree, academic status	Signature	Date
Nuclear power installation operation	Verhoturova V.V	PhD		

Abstract

Master's thesis contains 113 pages, 32 figures, 37 sources and 27 tables.

Key words: steam generator, steam humidity, height of steam volume, WWER units, evaporation surface, gravity separation, submerged perforated sheet.

The object of investigation is a steam generator of the WWER type with louvre separator.

The purpose of the work: deals with the influence of different separation schemes in the horizontal steam generators (WWER SG) of NPP on the quality of steam produced in the steam path for feeding to the turbine.

As a result of the research: an analysis of the factors determining the quality of the generated steam in horizontal steam generators of the PGV type was carried out. The methods of determination of moisture are examined of which one of the most important parameters affecting the moisture content of steam is the height of the vapor space. Their advantages and disadvantages are revealed. The history of the development of separation schemes for NPP units with WWER-1000 reactors was considered. The results of full-scale tests of PGV-1000 without a louvre separator was assessed which revealed certain advantages of this separation scheme. This was compared to calculated values for WWER 1200 with a louvre separator which showed that it may be possible to keep the louvre separator in a steam generator design in for a case where there is a problem with the submerged perforated plate.

Level of implantation: fully working on this thesis during 4th semester.

Cost-effectiveness/value of the work: high feasibility, does not require much cost.

Applied areas: this research can be well applied in areas, such as nuclear physics and engineering field. The result of the study presents some tables and graphs that provides useful information for nuclear engineers in modern steam generators design.

Future plans: apply to optimize steam separation characteristics of modern SG designs and to prolong the operational lifetime of SGs and the reactor plant as a whole.

List of abbreviations

SG	- Steam generator
WWER	- Water-water energetic reactor
CANDU	- Canadian Deuterium Uranium
PWR	- Pressurized water reactor
RSGs	- Recirculating steam generators
HTR	- High Temperature Reactor
NDT	- Nondestructive testing
S_S,	- Concentration of impurities in steam.
Y	- Moisture content of steam
TVA	- Tennessee Valley Authority
D	- steam generation capacity
P_2	- working fluid pressure
d_{in}	- inner diameter of the SG vessel
F_d	- disengagement area (steam relieving area)
L_{ls}	- length of the louvre separator
h_{ls},	- vertical distance from the inlet of the louvre separator to the SG vessel wall
h_w, h_a	- weight and actual water levels relative to the submerged perforated sheet
h_0	- elevation of the upper edge of the submerged perforated sheet
h_s	- height of steam volume
w_0''	- superficial velocity of the steam
ρ'', ρ'	- density of dry saturated steam and boiling water at pressure P_2
φ_{sq}	- actual volumetric steam quality when bubbling steam through a water layer
F_{spp}	- area of the submerged perforated sheet
A_{ls}	- width of the louvre separator

Contents

Introduction

A steam generator is a device or heat exchangers that uses a heat source to boil liquid water and convert it into its vapor phase, referred to as steam. The heat is produced as a results of combustion of a fuels. The ever-increasing population of the world continuously put demand on power. Due to this everyone is finding new ways of generating power for development of the world as a whole. Fuels comes in the form of petroleum, coal, biomass, natural gas, a nuclear fission reactor and other sources. The steam produced drives the turbines to produce power. The steam system serves not only to convey steam to the steam turbine but also to remove heat from the steam generator during shutdown and under abnormal operating conditions. This means that, even when the steam turbine cannot receive steam, there must be a removal path for it.

Different types of steam generators are in existence ranging in size from small medical and domestic humidifiers to large steam generators used in conventional coal-fired power plants that generate about 3,500 kilograms of steam per megawatt-hour of energy production. The smaller commercial and industrial steam generators are referred to as ″boilers″. In our life setting, domestic water heaters are also referred to as ″boilers″, however they do not boil water nor do they generate any steam.

The large steam generators used in current power plants to produce electricity are almost made of water-tube design, due to their ability to operate at higher pressures. The Calder Hall nuclear power plant in the United Kingdom was the world's first nuclear power plant to produce electricity in commercial quantities and began operations in 1956 [1]. The Shipping Port Atomic Power Station in Shipping port, Pennsylvania was the first commercial nuclear power plant in the United States and was opened in 1957[2]. As of 2007, There were more than 430 operational nuclear power plants worldwide and they produced about 15% of the world's electricity [3][4]. Nuclear reactors generally have high heat release rates per unit volume and a large quantity of circulating coolant. Steam generators used in nuclear reactors have unique designs and operating considerations. In the BWR and LGR (RBMK) steam is generated directly within the core of the reactor whereas in all other reactors steam is generated in a separate steam circuit. Pressure-containing parts of the steam generators are often made of carbon or low alloy steel [5].

The Daya bay nuclear power station that is sited in China which uses pressurized water reactor. In its steam generator, there are over 4,400 U tubes made of a nickel-chromium alloy. The coolant water that runs through the U-shaped tubes in bundle heats up the working fluid water on the outside. At a lower pressure, the water around the tubes becomes boiled to produce steam. The wet steam moves up through mechanical separators to eliminate moisture content from the steam. This reduces the moisture content so that the steam emerging from the top of the generator contains only 0.25% humidity, at 284º C and a pressure of 69 bar, to drive the turbines. The steam generators used weighs about 330 tons that is when empty with a height 21 meters, it produces about half a ton of steam per second [6]. Nuclear steam generating systems include a series of highly specialized heat exchangers, pressure vessels and pumps which use heat produced out of nuclear fission reactions to safely and effectively generate steam. This system depends on energy released when atoms within radioactive materials such as uranium, break apart(fission).

In commercial power plants steam generators, can measure up to 70 feet (approximately 21m) in height and weigh as much as 800tons. Each steam generator can contain anywhere from 3000 to 16000 tubes, each about three quarters of an inch (approximately 19mm) in diameter. Coolant which is kept at a high pressure to prevent boiling, is pump around nuclear reactor core. The coolant receives the heat out of the reaction in the reactor core. It is then pumped through some tubes in the steam generator. Heat from this coolant is then used to produce steam. The major anxiety in this present time is to come out with high-capacity nuclear power plants which are modest in the world energy and the development of a reliable steam generator which operates without failure. The arrangement of the steam generator and the design of its essentials must provide the required steam productivity and limitations in all working regimes of the nuclear plant.

Historically vertical steam generators are mostly used abroad and horizontal steam generators used by Russians. Both types of steam generators operate successfully in nuclear power plants and satisfactorily fulfill their purposes, enabling the production of electricity. The question of using different types of steam generator is raised periodically. There have been several attempts to scrutinize the existing concepts in one or another but it has led to no valid conclusions as to which is the best. It is impossible to select one or the other type of steam generator without making a wide-ranging study of the layout of the reactor facility and its scheme, servicing, and operation as part of a nuclear power plant. A comparative analysis of layouts of reactor facilities with different types of steam generators is made. Poor control of steam generator water level of a nuclear power plant may lead to frequent nuclear reactor shutdowns and this can lead a very large economical loss hence, development of better control schemes is very important.

Purpose of this work: In this work, the attention is focused on assessing the performance of modern nuclear power plant steam generators.

Objective of work:

1. A literature review on the operation of steam generators of nuclear power plants was documented considering their advantages and disadvantages of designs of steam generators.
2. Analysis of ways to address the negative effects in the steam generators.
3. Comparative analysis of steam generating path in the WWER units.
4. The identification of promising designs of steam generators for two-circuit nuclear power plants. The findings and conclusions.

1 Literature Review

1.1 The evolution of steam generators

The difference between a steam boiler and a steam generator has been always being confusing. In Steam Boilers Water is converted into steam by boiling at sub-critical pressures, the steam-generating equipment system is called a "Steam Boiler". Where as in Steam Generator, Water is Converted into steam without boiling at super-critical pressures, the equipment system is called Steam Generator. In this this section let us consider the evolution of steam generators.

In the early days of steam generators (late 18th century), fire-tube boilers began to be widely used for steam generation in industrial plants, railway locomotives and steamboats. Fuel combustible gas fuel products flow through tubes surrounded by water contained in an outer cylindrical drum and hence the name Fire-tube boilers. Today, steam-driven locomotives and river boats have virtually disappeared and fire-tube boilers are not used for steam generation in modern utility power plants [7]. However, they are still used in some industrial plants to generate saturated steam at pressures of up to about 18 bars and at rates ranging up to about 25,000 kg/hour [8]. This is because fire-tube boilers offer low capital cost, working dependability, rapid response to load changes and no need for highly skilled labor.

New developments that came was the Water-tube boilers with longitudinal steam drums [9]. This was developed to increase steam pressure that can be generated and increase its capacity. In water tube boilers, water flows through inclined tubes and the combustion product gas flows outside the tubes. This puts the wanted higher steam pressures in the small diameter tubes which could withstand the tensile stress of higher pressures without requiring excessively thick tube walls [10].

The nuclear-powered steam generator started as a power plant for the first nuclear submarine, the USS Nautilus (SSN-571). It was designed and built by the Westinghouse power company for the submarine from there the company started its development and research of nuclear powered steam generators [1].

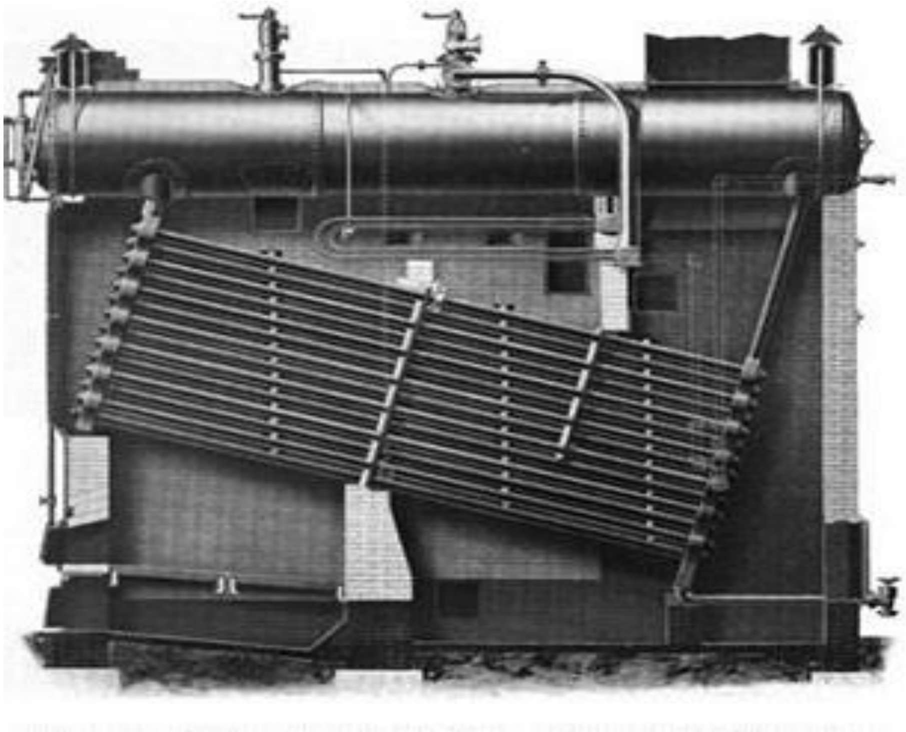

Figure 1.1 - illustrate a diagram of Bab and Wilcox Water tube boiler

Once peaceful nuclear reactors were legalized for use as power plants, some power establishments embraced the prospect to utilize the growing development of nuclear powered steam generators. The Yankee Rowe nuclear power station (NPS) also used a nuclear-powered steam generator in 1960. Their power plant was producing 100 MWe as output. Comparing to some modern plants which have over 1200 MWe output, it says it all that there has been development.

1.2 The modern kinds of steam generators used in nuclear power plant

There are many types of steam generators according to the reactor type. Boiling water reactors does not involve steam generators because the water boils directly in the reactor core. In other types of reactors, such as the pressurized heavy water reactors of the CANDU design, the primary fluid is heavy water. Liquid metal cooled reactors such as the Russian BN-600 reactor also use heat exchangers between a secondary sodium circuit and a tertiary water circuit. The requirements to be met by the next generation of power plants are subject to various criteria depending on regional considerations. Whereas efficiency together with environmental protection, availability and power generating costs head the list of priorities in the highly industrialized countries, investment costs and financing are becoming increasingly important factors in the growth countries.

A typical steam generator (vertical design) can measure up to 70 feet (~21m) in height and weigh as much as 800 tons. The NSSS (Nuclear Steam Supply System) is a relatively recent development and has been in use for about thirty years. During this time, there were constructed and put in operation 298 Pressurized Water Reactors (PWR), 81 of which are in the U.S.; 100 Boiling Water Reactors (BWR), 38 of which are in the U.S.; 19 light-water cooled graphite-moderated reactors (LGR) and 50 pressurized heavy water moderated and cooled reactors (PHWR)—all over 30 MW. In addition, there were expected to be in operation 163 more PWRs, 56 BWRs, 12 LGRs and 18 PHWRs [11].

In a typical water reactor, hot primary coolant with properties 330°C and 16MPa is propelled into the steam generator through a primary inlet channel. The high pressure is needed to prevent the water from boiling**.** The feedwater in the secondary circuit is heated to boiling point at approximately 280°C and at a pressure of 6.5MPa. The primary coolant water exits the steam generator with temperature 295°C and at a pressure of 16MPa through primary outlet and continues through a cold leg to the reactor with the aid of a coolant pump.

Steam generators of a power plant can be defined by the following parameters: type of SG (vertical, horizontal), steam output (saturated or superheated steam), number of steam generators (from two to six), number of drum separator (if present), tube shape (U tube or straight), tube material, SG shell material, drum separator shell material, design thermal capacity for single SG, design heat transfer surface [12]. Recirculating steam generators (RSGs), designed by Atomenergomash (Russia), Westinghouse (USA), Combustion Engineering (USA), Framatome (France), Mitsubishi Heavy Industries (Japan), and Siemens-Krafrwerke Union (Germany), among others. The Russian (WWER) designs with the Babcock & Wilcox (USA) once-through steam generator design and the Canadian designs. [13]. Every component of the nuclear power plant has its own basic requirement and the steam generator of no exception to this.

The tubes arrangements used in these forms of steam generator are of two major forms namely quadratic and triangular arrangements. Each of them may be inline or staggered and this is represented in Figure 1.2 below. Commercial power plants steam generators can measure up to 22 m in height and weigh as much as 800 tons. The steam generator can hold between 3000 and 16000 tubes with each about 19 mm in diameter. Kraftwerk Union (KWU) and B&W/AECL (Babcock & Wilcox/Atomic Energy of Canada Limited), design companies have their tubes produced of alloy 800.

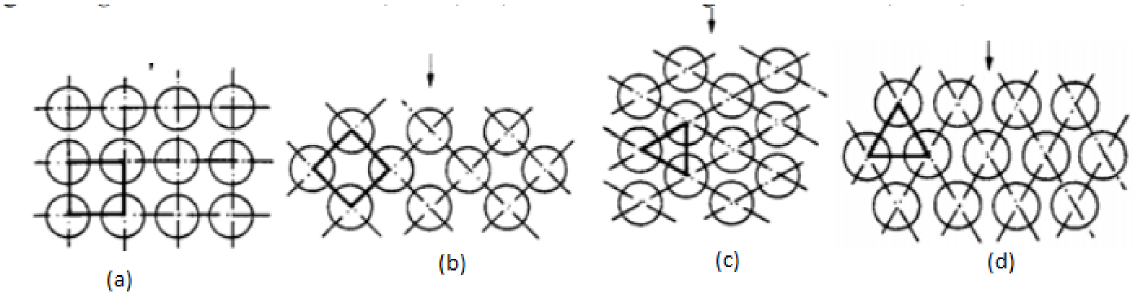

Figure 1.2 - Pipe arrangements: quadratic: (a) inline; (b) staggered; triangle: (c) inline; (d) staggered

1.2.1 The vertical steam generator

The name is as a result of the positioning of the steam generators. Generally, they have a feedwater inlet valve that supplies feedwater into the steam generator. The feedwater is directed downward and moves along a wrapper sheet then is directed to flow upwards the steam generator tubes. The water picks up heat and increases in temperature until boiling occurs and the water is then converted to steam with some little amount of water. The top part of the steam generator has moisture separator which separates water from steam [14]. This two-phase mixture rises up to steam separators. Normally the pressure on the secondary side is about 7.5 MPa. Vertical steam generators have been well understood over the years and have long been used in nuclear power plants with PWR in countries in the West and East.

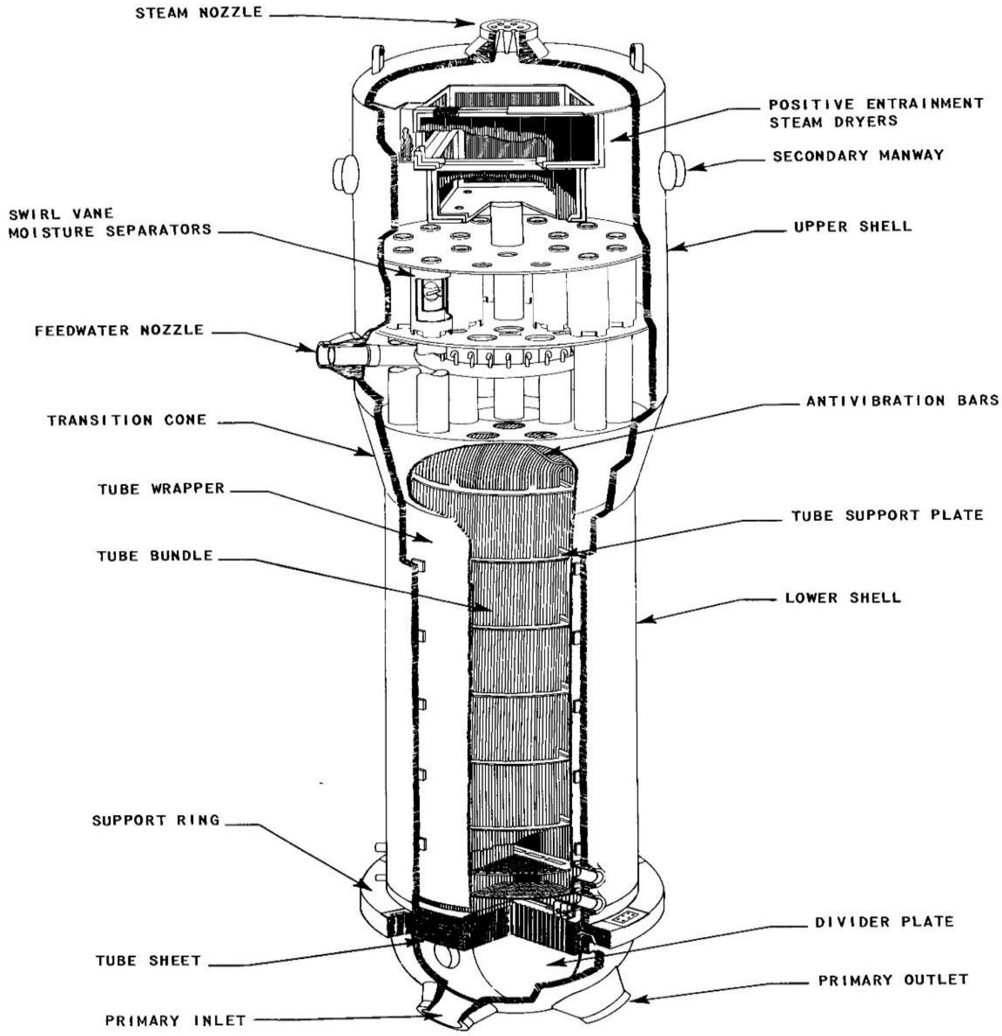

Figure 1.3 - Shows a labeled design of vertical steam generators

The very long tubes are vulnerable on flow induced oscillations and will vibrate touching each other or other structures if anti-vibration spacers are not used. This can lead to erosion or destruction of the tubes. An example for tube support planes is given on Figure 1.4 below. For anti-vibration bars in steam generators, stainless-steel has always been most appropriate for steam generator tube support structures.

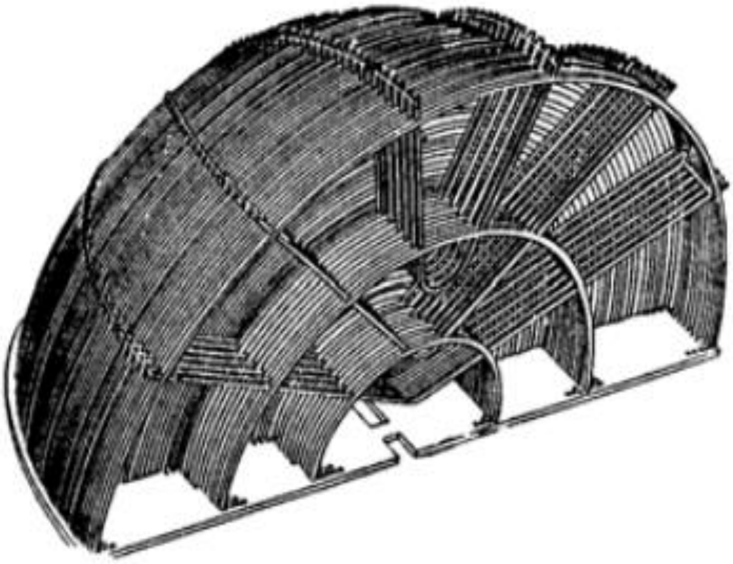

Figure 1.4 - Illustrate a diagram of antivibration bar arrangement for tubes

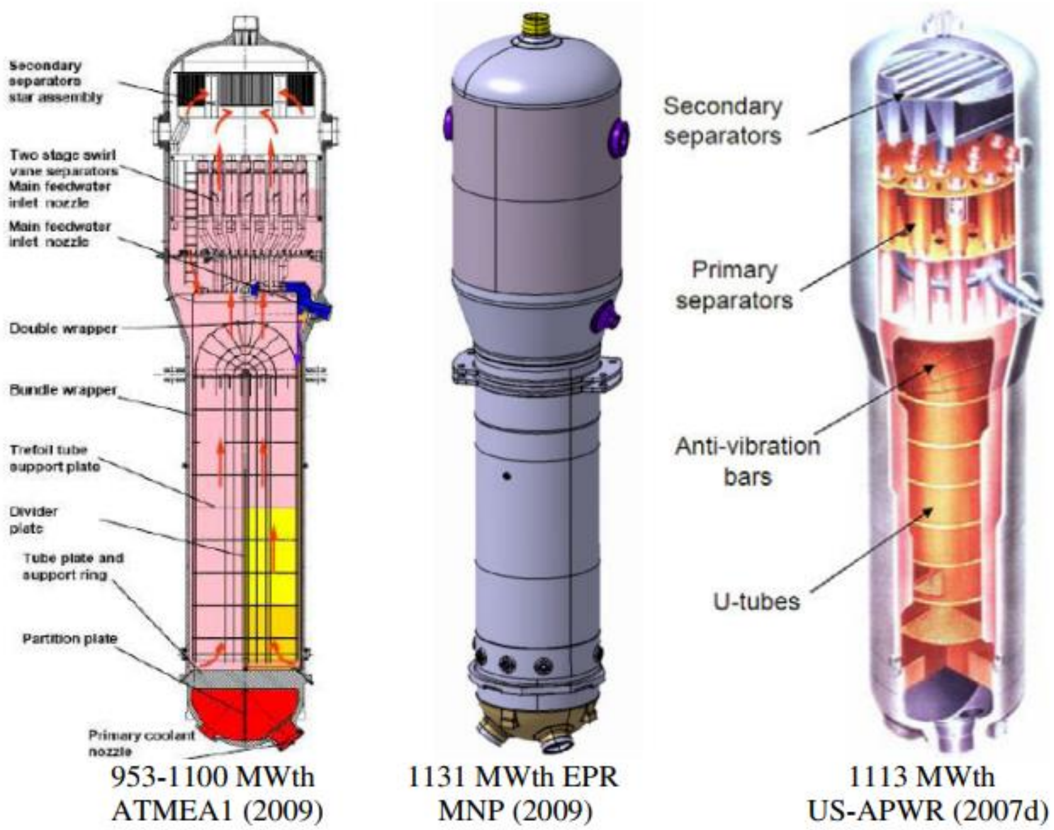

Figure 1.5 - The evolution design of vertical steam generator

1.2.2 The horizontal steam generator

The horizontal steam generators have their tubes positioned horizontally within the vessel. Reactor coolant flows through the tubes. The steam generator tubes are inspected for degradation and thinning using a non-destructive examination method known as eddy current testing. Probes are sent through the tubes and the signals from the sensor are assessed on a computer. If defects are found on any tube it is plugged out or a sleeve is fixed to toughen the tube. The tubes employed in the new forms of steam generators are produced from heat-treated Inconel 690 alloy.

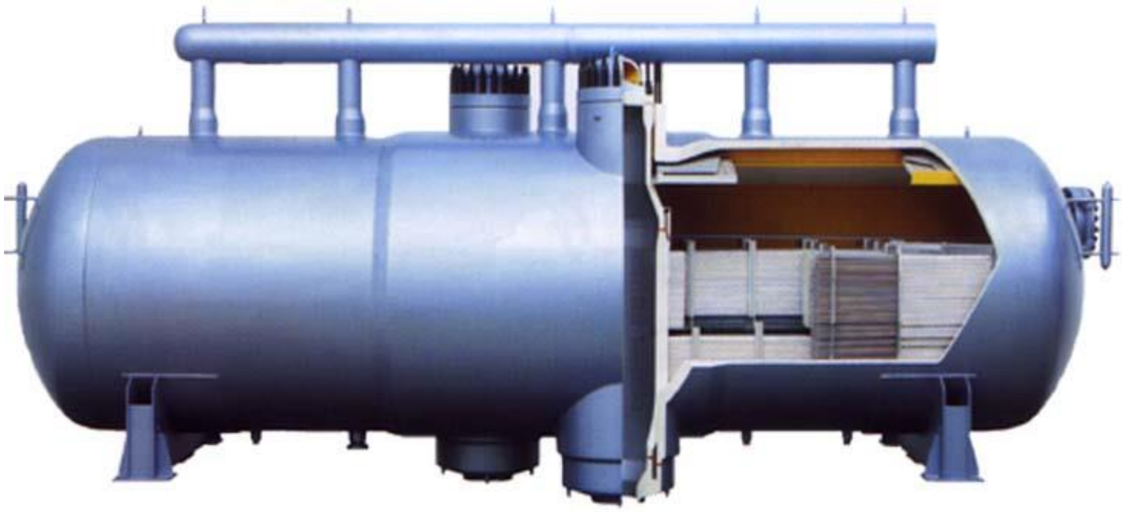

Figure 1.6 - Shows a design of horizontal steam generator with inside tubes

A characteristic and distinctive feature from the steam generator in nuclear power plants with WWER which uses the horizontal design is that Inconel 600 and 690 alloys or incalloy 800 with high nickel content of 75, 60, and 32%, respectively are used for the production of tubes in the heat-exchange section. The development, manufacturing and operation of new steam generators is as a result of experiences gathered from countries using different types of steam generators in power stations. An example is PGV-1500 which is designed with regards to the fundamental solutions to design problems of existing designs. The PGV-1500 new design possess all of the basic positive properties of horizontal steam generators. The most important modifications from the prototypes are discussed below [15]:

a. A corridor-construction heat-exchange bundle is used; this gives certain benefits over the checkerboard arrangement in PGV-1000. It improves the circulation features of the steam-water loop and the risk of plugging the bundle with sludges is decreased. It is easier to performs tests on the tubes and to reach the bottom rows of a bundle is made simple.

b. The heat-exchange tubes are manufactured of the alloy 03Kh21N32M3B and this alloy has higher corrosion resistance, which greatly increases its reliability and durability of the tube system particularly for instances where the operating and storage conditions are disturbed. This material makes the production of the tubes expensive however and the radiation conditions during servicing of the generator somehow more complex. The design reserve of the heat-exchange surface is smaller and consequently, the design is being industrialized as an option and can be delivered when it is needed by a customer.

c. The collector for removing steam (steam collector), which is present in all earlier existing horizontal steam generators, is eliminated; this makes it possible to transport it in an assembled state and to make it easier during assembly operations at the site of the nuclear power plant.

The circumstances for satisfying the strength standards considering the required technological and corrosion additions to the wall thickness limit the reduction in the wall thickness of heat-exchange tubes. Nuclear power plants with PWR the strength and additional reserves are much lesser, and this makes it viable to get a relative wall thickness about 1.6–1.7 times lesser than in nuclear power plants with WWER, and the pressure of the steam is correspondingly higher. The PGV-1000 is a modern form nuclear power plant with dimensions of tube to be 16×1.5 mm, and the dimensions of steam generators in nuclear power plants with PWR, specifically, of the type EPR, are 19.05×1.09 mm with almost same mechanical properties of the materials. For steam generator tubes in a WWER reactor design the critical size of a longitudinal flaw is much greater and such a defect is more easily revealed by finding a leak or by nondestructive methods, and this permits preventative plugging of the defective tube. This does not allow the tube to rupture to a large extent and lower possibility of emission of radionuclides into the surrounding environment. Therefore, reducing the thickness of the wall of the tubes, on the one hand, increases the thermal efficiency and, on the other hand, reduces consistency and safety due to the higher probability of rupture, which has occurred recurrently in nuclear power plants with PWR. For the operative standards of the Russian WWER, the maximum possible reduction of the wall thickness is as a result of more stringent tolerances and other factors which does not exceed 0.2 mm thickness. This makes it probable to increase the pressure by not more than 0.1 MPa. Without making a thorough comparison of the types of steam generators in use we consider the advantages of the modern horizontal steam generators (WWER design):

1. They operate on moderate steam load on the evaporation surface (0.2–0.3 m/sec) and this allows the incorporation of simple separation scheme with allowable amount of moisture in the steam.
2. They have moderate velocity of water in the second loop (up to 0.5 m/sec) which removes the risk of vibration of the heat-exchange pipes and other components.
3. The heat exchange tubes are made of corrosion-resistant 08Kh18N10T austenitic steel with a little nickel content which has been validated for the adopted water-chemistry regime; experiences gathered from the operation of the WWER PGV-440 and WWER-1000 steam generators (working for more than 30 years) approves that it works;
4. The vertically designed cylindrical collectors in the first loop helps to avoid the buildup of sludge deposits on the tube surface. This leads to lessening the risk of corrosion damage to the coils near the points of attachment in the first-loop collectors.
5. The horizontal steam generators allow for more water storage which becomes beneficial to make way for more cooldown of the reactor when normal and emergency feeding of water break. The large storage capacity softens transient working regimes of the reactor system;
6. The principle of stepped evaporation makes enables to maintain the concentration of dissolved scums in the critical zones which is far below the balance

concentration in the purge water; this further make operations more reliable from the corrosion point of view.

7. The modern arrangement of the heat-transfer surface provides good natural circulation of the medium along the first loop even when the mass level of the water goes below the top rows of the heat-exchange tubes;

8. Satisfactory conditions for natural circulation in the first-loop coolant during an accident occurrence has been considered. Accumulation of noncondensing gases, which avoid coolant circulation, is prevented; the presence of large gas accumulators (up to 0.5 m3) at the top of vertically-arranged coolant collectors makes it feasible to provide easy discharge of the gas from the tubular bundle into the designed gas-removal systems;

9. Suitable access to the tube sheet for servicing and checking is created; there are no heat-exchange tubes at the down part of the vessel where sludge can settle and accumulate; for instance, corrosion-active impurities that accumulate at the bottom of the vessel can be easily washed off through the purge system and specially designed pipes;

10. The welded parts of the unit which is subjected to pressure are accessible for checking, as provided by the documentation, and repair. A functional system of monitoring, diagnostics, and repair equipment is used and this permits technical servicing and eradication of any defects.

11. The equipment for disconnecting the steam generator from the main circulation pipeline of the coolant has been mastered to make possible to reduce considerable time required for planned maintenance and increases the installed capacity utilization factor.

Once-Through is a form that is well noticed. The once through concert or the OTSG Unit introduces feedwater at one end of the tube and it goes through the process of heating until it gets superheated then steam is produced from the other end. This steam generator used here are normally characterized by high steam - water velocities, to reduce metal temperature differences along the tube. This form of steam generator unit is a single tube exposed to heat source. The quality of the mixture changes along the length of the tube, being zero at the inlet end and reaching 100% at some point in the length of the tube at which point superheating begins. It is vital to make effective use of the heat transfer surface for this reason, it is vital to maximize the nucleate boiling. In this type, boiling steam bubbles form where there are cutoffs in the heating surface. These bubbles break off and are pushed out by the movement of the steam water mixture [16]. Steam generator manufacturing companies make use of the once through design concept to build steam generator units because of its simplest form.

1.2.3 Tubing of steam generators

The selection of tubing materials for nuclear heated steam generators is a subject which has continually been under study to ensure that the best material could be used for better materials for application in the all types of reactors. A normal heat-exchange bundle has four packets between which down corridors are planned. In the U-tube heat exchangers, tubes angles are increased from 60 to 100, 130, and 200 mm, which reduces the degree to which the metal is deformed and makes it more expedient to check the tube sheet metal by automated means. Feedwater that is supplied in the steam generator is done in a way so that some of this water covers the tube bundle, and some enters the inter-tube down corridors through the vertical perforated tubes in order to make circulation in the second loop efficient. An ever-open separation scheme is used and this scheme has been examined during operation of horizontal steam generators and dependably supplies steam with some level of moisture content in a wide range of the working water level. We will indicate some few properties of the presently known candidates in order of their relative costs.

1. Carbon steel has been considered and has excellent potential however, carbon steel is subject to pitting attack under lack of chemical control.
2. Monel has proven itself in nuclear service but tends to produce some copper activation products which are undesirable.
3. Incoloy appears to be an excellent material but ~here is no known relevant heat exchanger service.

4. Stainless steels were used in all the original PWR systems but stainless steel is subject to chloride stress corrosion.

5. Inconel is widely used and until recent months, had no known history of stress corrosion or other defects in service.

The heat-exchange tubes have designs according to the type of steam generator and are mostly arranged in bundles. The big spacing corridor arrangement of the tubes in a heat-exchange bundle allows the following:

1. Increasing the force of circulation of the water in the tube bundle, and this will in turn reduce the probability of deposit formation on heat-exchange tubes, concentration of corrosion-active impurities underneath the tubes, and the likelihood of impairment to the heat-exchange tubes.

2. Reduction or elimination of the possibility of sludge blocking the inter-tube space and to facilitate sludge removal if the need be. This goes on to allow for easy inspection and cleaning of the tubes.

3. Increase the technological success of tube repair (plugging) through the process of welding.

4. Increase the water stored in the steam generator and with the water-chemistry regime at the present level, increases the life span of the steam generator up to 50 or more years.

With respect to issues concerning tube plugs, a general practice is to physically review Hot Legs and Cold Legs tube plug during outages in order to identify leaking tube plug welds during these inspections. Tubes with poor plug welds could undergo pressure and fail due to tube degradation if it is proceeded. This delinquent contributes to primary to secondary leakage if tube contains a leaking defect. Tube fouling may lead to decrease in solubility of magnetite in heavy water with decreased temperature, causing Magnetite deposits in SG tubes and from a safety perspective, deposits can influence tube inspection proficiencies. Tubes may become obstructed thereby preventing tool passage, and magnetite deposits may affect the detection of the defect and sizing. Foreign materials that remain in the primary side of SGs could cause scratches on tubes and create a possible initiation sites for in-service degradation. Moreover, materials could be transported through the circuit and into reactor [17].

Tube supports normally made of carbon steel plays an important role in steam generators and to this reason it must be well kept and monitored. Amidst these safeties they are being exposed to a variety of degradation mechanisms, as under deposit corrosion and cracking of U-bend bar supports; corrosion of tube support plates causing tube denting and loss of tube support; tube fretting at supports.

1.2.4 Structural design and analysis of the vessel

The design for steam generator which are used in the United States must meet some criteria and in order to meet the requirements of the ASME Code, Section III Class C. The primary section of the circuit must be designed to ASME Nuclear Code Section III and the Secondary section must be design to meet the ASME Unfired Pressure Vessel Code Section VIII Division 1. The primary section of the steam generator which is designed in the form of a "light-bulb" comprises of the inlet head, tube sheet and tubes while the secondary section contains of the shell upper head light bu1b section and main steam outlet nozzle. The primary side of the steam generators must undergo a complete stress analysis and a stress report issued documenting this analysis.

Fundamentally, the Power Boiler Code Section 1 or Unfired Pressure Vessel Code Division 1 Section VIII does not call for a detailed stress analysis but simply set the wall thicknesses necessary to keep the basic hoop stress below the allowable stress. They do not require comprehensive evaluation of the higher more localized stresses which are known to exist, instead goes for the safety factor of four and a set of design rules. These basic procedures are mostly for conservative for pressure vessels in conventional service and a thorough study of many pressure vessels constructed to the rules of Section VIII have showed that, where the design could be improved to save metal. However, for vessels to be used in severe types of service such as highly cyclic types of operation, for services which require higher dependability, or for nuclear service where periodic inspection is usually difficult sometimes impossible, extra design considerations are essential. Due to the improved development of analytical and experimental techniques and the use of computers, it is achievable to determine stresses in considerable detail. The complete stress analysis work must be completed requiring the use of a computer and the availability of design programs to analyze and prove that stresses are within the stated limits for the primary pressure parts. It cannot be said that a primary vessel built to Section III is designed before it is built, it is sized earlier before material is manufactured, but the design process continues during the engineering and manufacturing.

1.3 Designs of currently used steam generators

Steam generator can be constructed in horizontal implementation, or in vertical implementation which occupies limited floor space. The control panel and instrumentation with its full documentation is a major component which is monitored. The steam that is generated from the steam generator must be unpolluted and also non-radioactive, as it streams out of the containment structure. Since the primary fluid contain many radioactive material, it is of great importance to separate the two fluids completely. For this reason, the integrity of the tubing is essential in minimizing the leakage of water between the two sides. To increase the amount of heat transferred and the power generated, the heat exchange surface must be maximized. This is obtained by using tubes. A steam generator can hold between 3000 and 16000 tubes, with each about 19mm diameter.

The secondary fluid typically known as the working fluid is always water whiles the reactor coolant is carbon dioxide, sodium, helium etc. which depends on the reactor type. Considering some types of reactors such as the PWR, Where the coolant is pressurized water, there are different methods that can be used. The first of these, the working fluid flows through straight tubes welded to tube sheets at both ends. This is called the "once-through" type of steam generator. To reduce the loads exerted on the tube sheets by differential thermal expansion between outside shell and the tubes, a second method is every so often hired. This second approach handles the thermal expansion that occurs by using U-tubes welded to a tube sheet. Commercial nuclear power plants have between 2 and 6 steam generators per reactor. The materials that are used to design steam generators and it tubes are specially made to endure the heat, high pressure and radiation. The water supplied to the steam generators must be very clean and free of chemicals. In the boiling environment of the steam generator these chemicals can result in undesired corrosion. Steam generators are positioned in pairs within sealed volume boxes and Each normally mounted on supporting structures. To avoid disasters like earthquake, steam generators are released by means of hydraulic shock absorbers 17 [18].

1.3.1 The Russian WWER steam generator designs

Steam generators used in the Russian designed WWER plants are horizontal shell-and-tube heat exchangers manufactured by ZiO (Podolsk, Moscow Region), Atommash (Volgodonsk, Volgograd Region) and Vitkovice (Czech Republic). They are made up of a pressure vessel, horizontal heat exchange tubes, two vertical primary collectors, a feedwater piping system, moisture separators and steam collector [17]. The horizontal tubes in bundles with U-shapes is connected to the heating coolant collectors, manufactured out of stainless steel. The SG vessel is made of carbon steel. There is access to the collector from the top, through a flange joint in the vessel neck. The tube bundle supports are made of stainless steel.

A Primary coolant comes into the steam generator through a vertical collector and moves through the horizontal U-shaped submerged stainless-steel tubes. This leaves through a second vertical collector. The tube ends are attached to the collector wall and are expanded by means of either a hydraulic or explosive expansion process. It is welded from the inside wall of the collector. The collectors used in WWER consist of stainless steel or low-alloy steel with higher tensile properties, clad with stainless steel. The steam generator vessel is made of carbon steel or low-alloy bainitic steel. In a WWER- 1000 steam generator, the feedwater is supplied to the top of the hot side of the tube bundle under a submerged perforated sheet. The tube bundle is completely submerged.

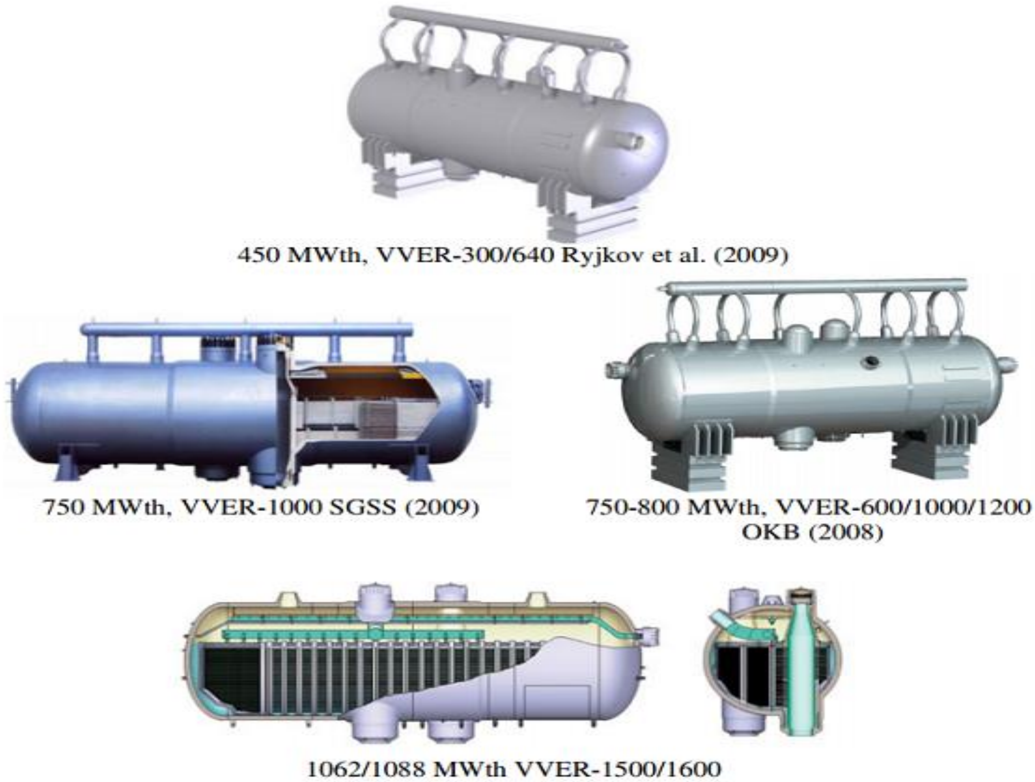

Figure 1.7 - Shows evolution designs of horizontal WWER with their thermal power

Considering that of WWER-400, feedwater is supplied to the middle of the tube bundle by perforated piping [18]. The distance between the tube supports is 700-750 mm. The WWER designs mostly have similar designs except for some few features which discussed below;

a. The size of the steam generator for instance the WWER-1000 steam generator is about 4 meters longer.
b. The arrangement of the tubes in the steam generator (corridor versus staggered).
c. Material used to manufacture collectors.
d. Location of feedwater supply.
e. The availability submerged perforated top plate (WWER-1000 only).
f. The arrangement of the steam dryer in the generator.
g. Emergency feedwater distribution system (WWER-1000 only),

h. steam header arrangement
i. The material used in the production of vessel.

A new development is the improved version of the WWER-1000 and this is called the WWER-1000U which has the perforated region of the collectors fabricated from austenitic stainless steel. The development of the design types of steam generators is as a result of challenges arising during operation of the steam generators in nuclear power stations. Both concepts of steam generators are following steady directions with a rich history, including successes and errors. The feeble spots in the designs were found during operation and they have been continuously been worked on as experience was gained, but the major price was often replacement of the steam generators.

1.3.2 CANDU steam generators

The CANDU steam generators comprise of an inverted U-tube bundle inside a cylindrical shell. It uses heavy water as coolant which passes through the U-tubes [19]. The steam generators used in CANDU can include an integral pre-heater on the secondary side of the U-tube outlet segment and integral steam-separating equipment which can located in the steam drum overhead the U-tube bundle. The primary coolant is directed through the U-tubes starting as saturated with a certain percentage of quality. It becomes sub-cooled as it transfers the heat to the secondary circuit. The secondary coolant (feedwater) enters sub-cooled (zero mass quality, i.e., negative thermodynamic quality) and, as it collects heat from the primary circuits, heats up to saturation temperature. The secondary coolant thereafter boils as it obtains more heat through the steam generator. The state at the primary coolant temperature where the secondary coolant temperature gets to saturation is called the “pinch point”.

The steam generators working used in CANDU reactors are vertically built and by Babcock & Wilcox Canada Ltd. The only exemption is the Wolsung 1 unit in the Republic of Korea which uses similar steam generators built by Foster Wheeler. CANDU RSGs are very similar to the PWR RSG with some differences in size, materials, operating temperatures and tube support structure. The steam generators used in CANDU reactors operate at lower temperatures (290°C to 310°C primary inlet temperature). The lower temperatures normally delay the start of thermally activated corrosion processes. The fact that primary coolant in a CANDU reactor is heavy water (D_2O), relatively small tube sizes 12.7 mm and, in current units, 15.9 mm is used to minimize the heavy water inventory. The issue with smaller size of the tubes is primary the difficulty in carrying out maintenance activities such as tube inspection and removal. The widely-used tube wall thickness falls within 1.13 mm and 1.2 mm and this depends on the type of alloy used in the production of the tube. One special thing about the CANDU design is the selection of tube material. The CANDU steam generators presently function with tubes manufactured out of high temperature, mill annealed Alloy 600, Monel 400 and titanium stabilized Alloy 800. These materials are liable to different types of degradation [20]. Each steam generator has eight connections for blowdown from the down comer area, two connections from the tube free lane area and four connections from the preheater area. Blowdown is used as a part of control of steam generator water chemistry. Steam generators will be blown down continuously to the condenser water outfall via a blowdown tank at the rate of 0 to 3% of full power steaming rate.

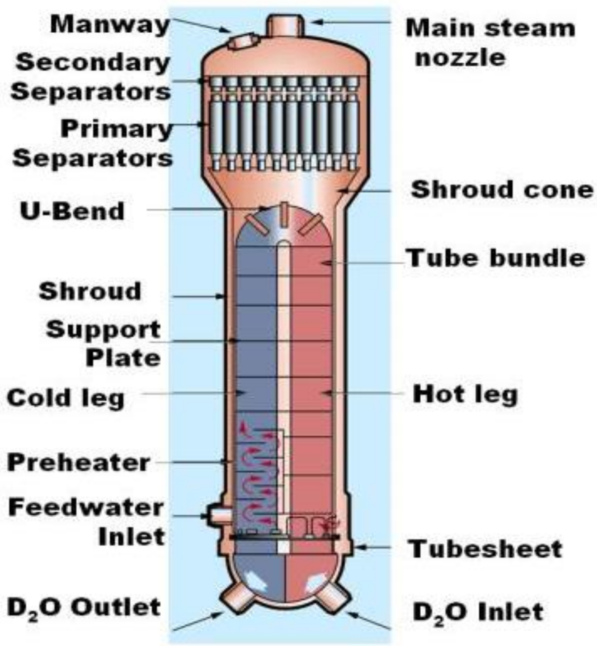

Figure 1.8 – Illustrates a CANDU nuclear reactor design

1.3.3 Advanced gas cooled reactors steam generation

The Gas Cooled Reactors (GCR) are forms of reactors that uses Inert gas, e.g. helium or carbon dioxide as the coolant and the moderator is graphite. The AGR is a design developed out of the initial Magnox gas cooled reactor. No further change has taken place for the AGR design. The plus of the design is that the coolant can be heated to higher temperatures than water. Due to this, an enormous plant efficiency (40% or more) is gained as compared to the water-cooled design which has about 33-34% of efficiency. Boilers are positioned around the reactor core within a concrete pressure vessel. The carbon dioxide gas that circulates through the core of the reactor, reaches a temperature of 650°C and then moves past steam generator tubes outside it, but still inside the concrete shield walls. Material used in kinds reactor’s steam generator and piping systems are Mild Steel, Annealed 9Cr-1Mo steel and 18Cr-12Ni SS [21]. Gas circulators in the lower part of the pressure vessel walls drive carbon dioxide coolant around the circuit. Each of the four steam generators is divided into six independently fed "half units".

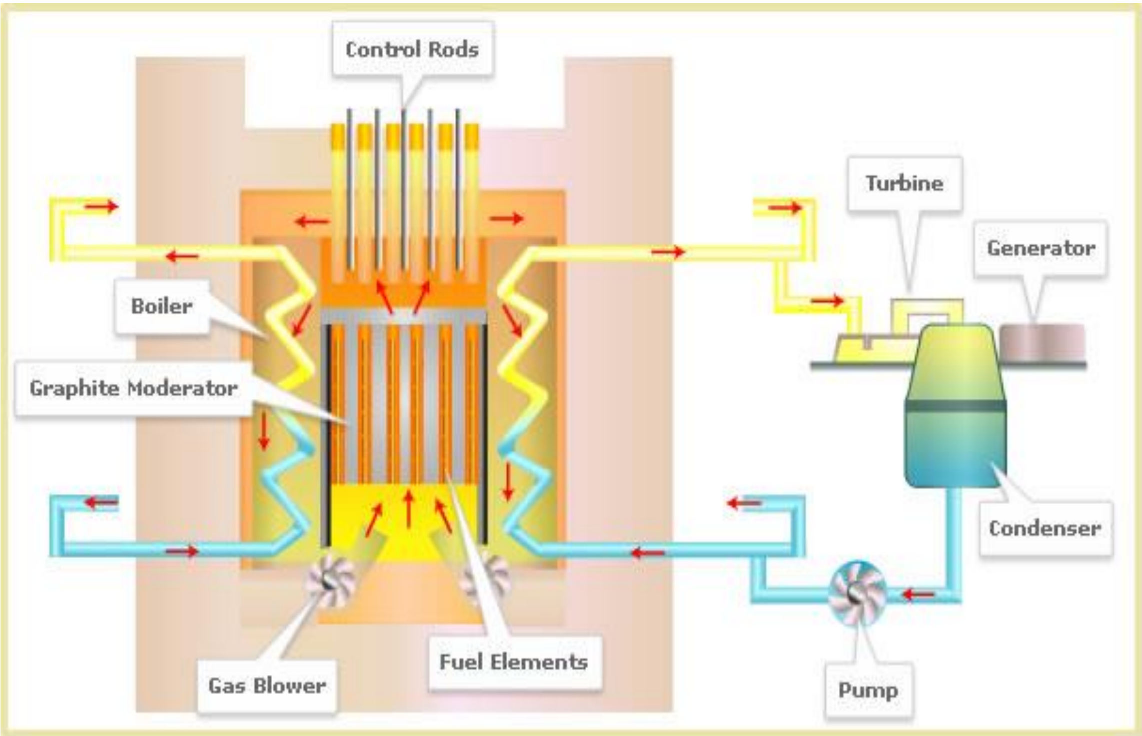

Figure 1.9 - Shows an advanced gas-cooled reactor design

1.3.4 High temperature reactor HTR

The High-Temperature Reactor (HTR), developed in Germany as a pebble bed reactor. The pebble bed core consists of spherical fuel elements walled by a cylindrical graphite vessel which serves as neutron reflectors. The High Temperature Gas Cooled Reactors are the new kinds of gas cooled reactors. This new design makes use of higher operating temperatures to further improve thermal efficiency of the reactor.

In an HTR nuclear power plant, the SG tube side is filled with water and steam, while the shell side contains high temperature and high-pressure helium. As comparing the heat transfer ability of helium to water, that of water is very low. A helical tube is used as heat transfer tube in HTR. considering HTR- 10 as an example, the steam generator is combined to the primary system and arranged in the reactor pressure vessel directly overhead the reactor core. The arrangements allow the medium flows through the heating surface bundles on the primary side from the lowest to the top part. Primary helium cools from 700 °C (70 bar) to 250 °C in the process. In the steam cycle of HTR, the pressure on the secondary section is higher than the helium pressure on the primary section. The heat transfer tubes are in three sections, the warm-up section, the phase-change section (with diameter of 18 mm and thickness of 3mm) and the superheated section. The superheated section with a diameter of 18mm and a thickness 2mm is the final section. The tube bends at a radius of bending radius of 56mm. These tubes are connected to each other by butt-welding. [22] The steam generator is mostly made of Alloy 617 and Alloy 230.

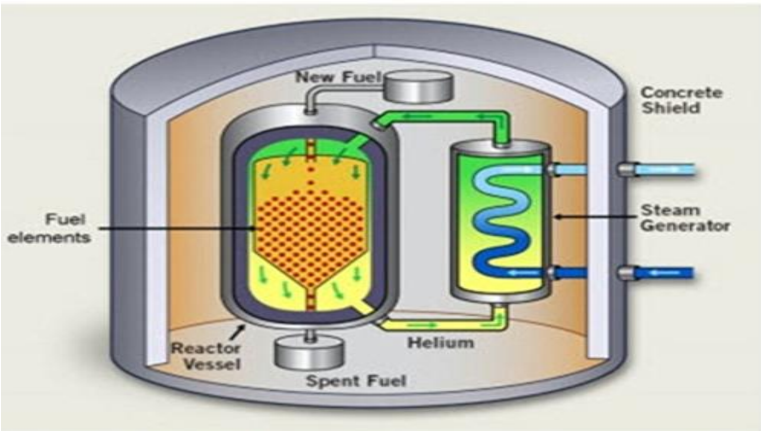

Figure 1.10 - High Temperature Reactor design

1.4 Moisture separation

It is important to reduce moisture content of the steam as low as possible to avoid damage to the turbine blades. Moisture (water droplets) in the steam, which is generated in steam generator's evaporator contributes to: erosive-corrosive wear of steam inlet components of a turbine; coverage of turbine blades, pipelines with saturated steam salts; fouling deposits on the surface of SG superheated tubes. These factors lead to roughness growth and reduced efficiency during heat transfer.

Some steam generators must employ multiple stage moisture separation. In the vertical steam generators two stages of moisture separation is performed. The first one causes a spin of the mixture which sways the water to the outside. The water which is drained is used to produce extra steam. The dried steam is routed to the second stage of separation where water and steam changes their direction of movement. The steam has an ability to change direction but water doesn't have that ability. The two-stage process of moisture removal is so efficient at removing the water that for every 100 pounds of steam that exits the steam generator, the water content is less than 0.25 pounds.

The Russian WWER (PWR) units employ a steam-turbine cycle with saturated steam of a relatively low pressure (less than 7 MPa). At such parameters, saturated steam is contaminated only due to the presence of water droplets with dissolved salts and insoluble impurities (solubility of salts in pure steam is almost zero). At high pressure (exceeding 7 MPa) the content of some substances (iron oxide and silicic acid) in steam rises significantly; a substantial amount of these substances is carried over from heating surfaces with steam.

The Main separation drum consists of a good number of components but the most important parts are submerged perforated plate whose purpose is to provide uniform loading of evaporation surface it is normally positioned between 50 and 75 mm lower the mass water level. It also has perforated hole which serves as the passage hole for the steam with diameter greater or equal to 10 mm. It has flanges to serve as support and allow easy movement of the plate. The second which is the separator separates water from steam in order to get lower moisture content in the steam. The final one is the steam-receiving perforated plate which receives dry steam that is steam with low moisture content. Steam separation widely used is of three forms namely gravitational, centrifugal and louvre separation.

Figure 1.11 – Damage and Characteristic deposits caused by moisture

It should be noted that the improvement of the separation characteristics of the horizontal steam generators of the NPP did not happen immediately. Initially, as the main scheme was used with a louver separator. However, in the early 2000s, it became clear that more powerful NPP units required an increase in the reserve for steam production, the expansion of the allowable range of change in the level of the evaporation surface. At the same time was discovered the inefficient use of louver in SG with preliminary gravity separation above the bubble layer in conditions of natural convection two-phase working medium. Then actually turned away from two-step steam separation in favor of a single-stage by replacing the louver on the perforated shield plate. Louver separators are used only in WWER-440 while in WWER-1000 and 1200 they are all replaced by a ceiling plate shields. The steam moisture separation methods will be discussed below.

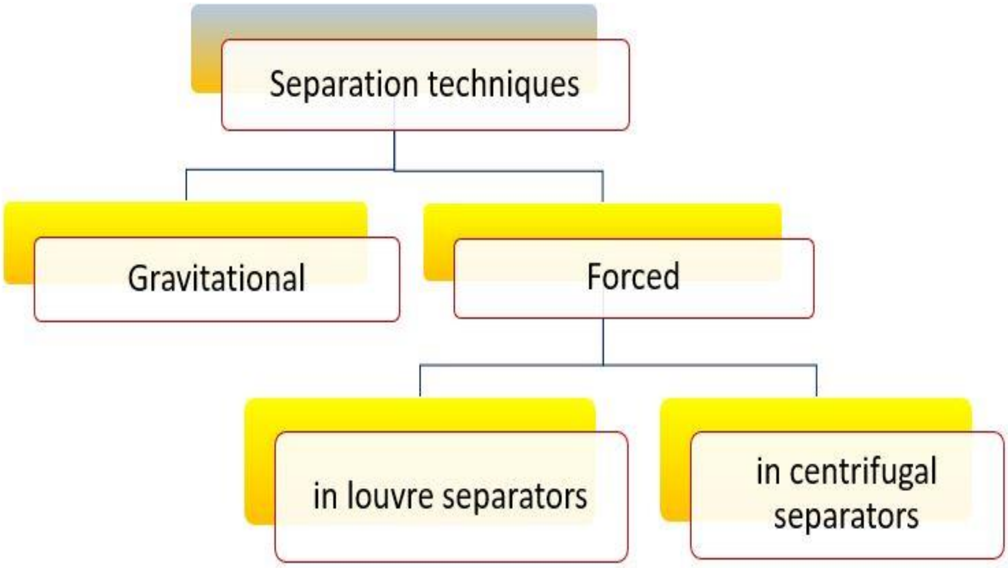

Figure 1.12 - Flow diagram of moisture separation techniques

1.4.1 Gravitational separation method

This form of separation mostly employed by the Russian WWER design and works on the basis of gravity. As the dried steam moves up, the water content drops down due to its mass and height. The main factors that govern the efficiency of gravitational separation:

– superficial steam velocity.

– height of steam region.

– uniform loading of evaporation surface.

– chemical composition of SG water.

The main factors determine the moisture content of the steam are the reduced velocity of the steam above the evaporation surface (steam generation capacity), the height of the steam region. The height of the steam region is the space between the boiling water surface and the louvre separator. The properties of water and steam, that is the pressure in the volume of the steam generator is another import factor. For a prescribed pressure, the moisture content of the steam changes with height above the evaporation surface for the reason of the different height to which drops jump. The variable jump height, in turn, is subjected to the size of drops, which is determined by process of the production of the drops: bursting of a bubble moving through the interface between the phases which is the evaporation surface, passage of a steam-droplet flow through leveling or steam-washing setups, forced initial separation giving an example as in bubble-less attachments of an immersed perforated sheet. The jump height will be determined by the reduced velocity of the steam in the steam region [23].

1.4.2 Louvre separation

Horizontal louvre separator represents an array of waved plates of 1mm thickness, with width between 80 and 100 mm. Waved channels provide for centrifugal effect, which results in liquid precipitation on the surface of separator plates. Separated liquid flows down the plate surface while dried steam moves upwards towards the perforated steam receiving plate. The main influences that determine the efficiency of louvre separators are steam velocity at the entry of louvre separator and moisture content of steam at the entry of louvre separator. This amount should not be more than 5 %.

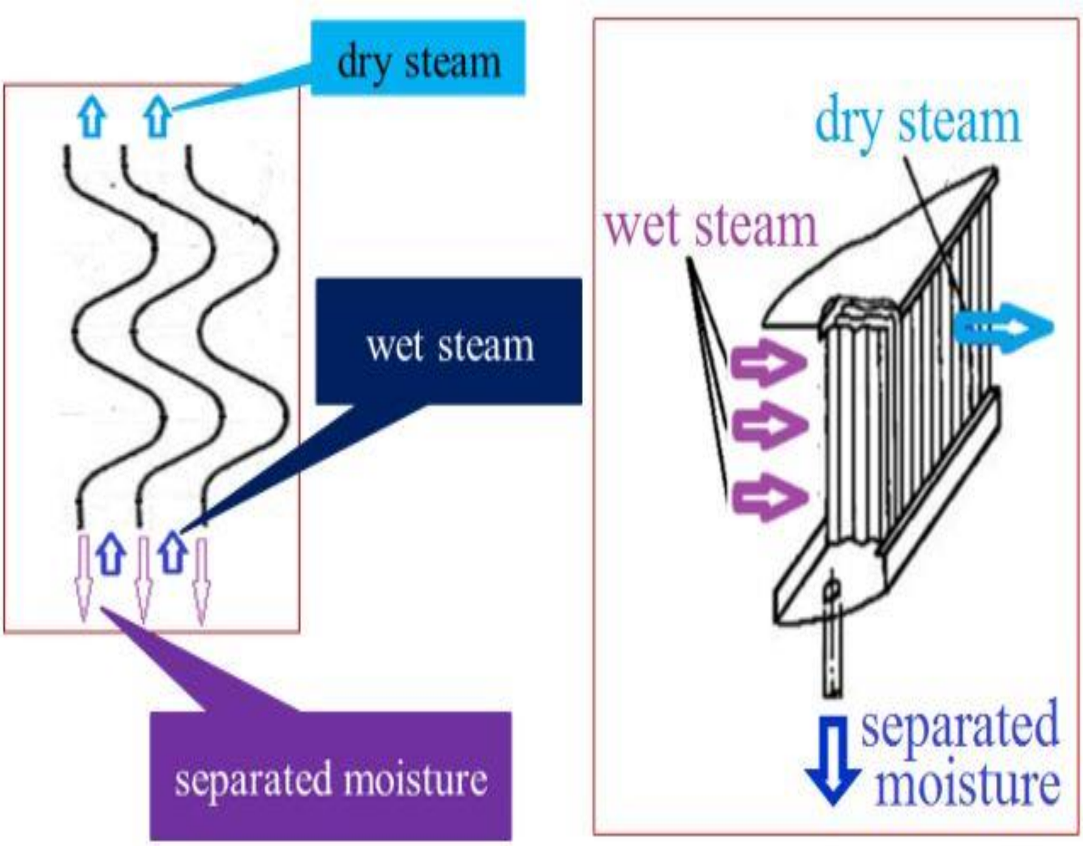

Figure 1.13 - Diagram describing a louvre separator

Table 1.1 - Advantages and Disadvantages of louvre separation

Advantages	Disadvantages
1. High efficiency of steam drying; 2. High operation reliability; 3. Low hydraulic resistance; 4. Design, manufacture, and installation simplicity.	1. Metal-intensiveness; 2. Complicated removal of separated water

1.4.3 Centrifugal separation

Centrifugal separation devices (cyclones) are useful in vertical SGs of Pressurized Water Reactor Nuclear Power Plants. The operation principle of the centrifugal separator can be discussed a steam-water mixture is supplied to the inlet nozzle and then, to the vane swirler where it is given a swirling motion. Water is thrown onto the walls of the separator vessel by centrifugal force and as a result of their mass water is removed from the separator through holes. Steam travels from the separator to the steam region and the separators are fixed on the plate over the tube bundle. Normal process of a cyclone depends on the correct selection of steam flow rate and steam flow rate for a typical size cyclone is uniform. The advantages of the principle of centrifugal separation are that, they are effective and compact which make a good method. Amidst the mentioned advantages, it has a disadvantage which is considerable hydraulic resistances. Due to the inevitable pressure drop in the steam line leading to the turbine, the water content will slightly increase before the steam reaches the turbine end of the line. However, according to the invention we locate the main drying equipment in the steam line between the steam generator and the turbine, shortly ahead of the turbine inlet, and we employ for this purpose a water from-steam separator such as a cyclone or other centrifugal separator system. As a result, the turbine receives the virtually fully dried and saturated steam issuing from the dry-steam outlet of the main separator vessel.

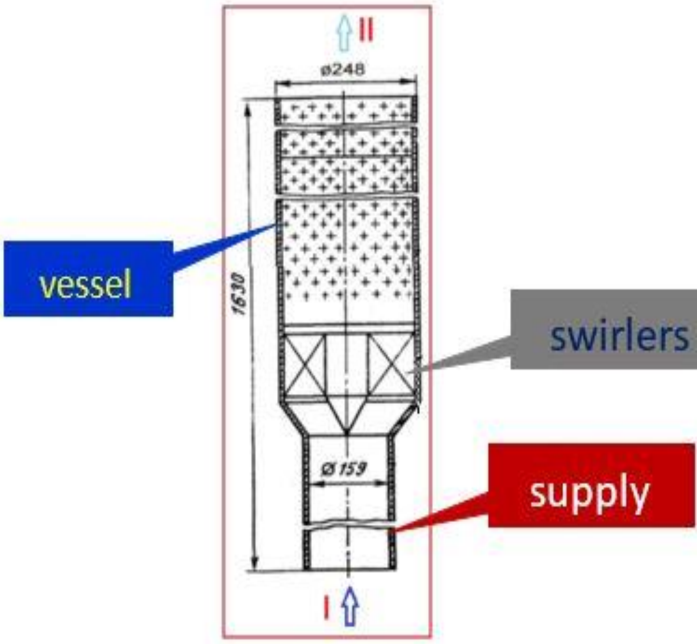

Figure 1.14 - Shows a swirler used in centrifugal separation

The labeled Cross-sectional designs of the horizontal U-tubes and vertical steam generators are presented in diagrams below to describe how separation occurs SG. Some designs tend to combine different forms of separation techniques to improve the moisture separation process.

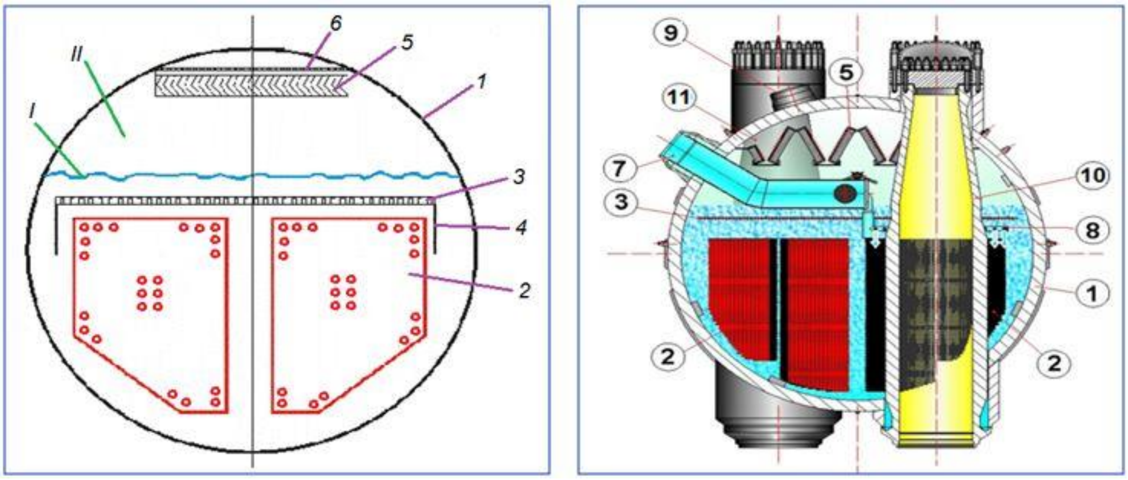

Figure 1.15 - Shows a cross section view for steam separation in steam generator: 1 - vessel; 8 – feedwater distribution system; 2 – heat-exchange tubes; 9 – steam outlet nozzle; 3 – submerged perforated plate; 10 – hot coolant collectors (headers); 4 – flanges of submerged perforated plate; 11 –cold coolant collector; 5 – louvre separator; 6 – steam-receiving perforated plate; 7 – feedwater supply nozzle; I – evaporation surface; II – steam region.

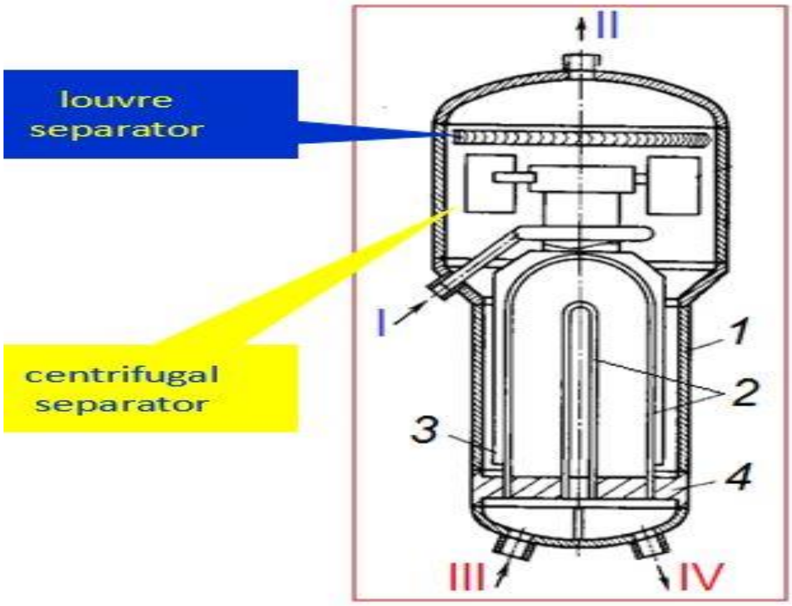

Figure 1.16 - Shows steam separation in vertical steam generator: 1 - vessel; 2 – heat-exchange tubes; 3 – partitive shell; 4 – tube sheet; I, II – feedwater inlet, steam outlet; III, IV – coolant inlet and outlet.

1.5 Steam generator degradation

The problems related with steam generator degradation has significant impact on nuclear power plant operation. Utilities with degrading steam generators must make a compromise between either continued operation with high operation and maintenance costs. This also comes with high radiation exposures to workers and increased risks of forced outage from tube ruptures. The second option is replacing the steam generator.

Operating practice of WWER and PWR NPP SGs reveals that the main element that determines their actual lifetime is heat-exchange tubes. To eliminate the possibility of primary coolant leakage into the secondary circuit, all SGs undergo regular eddy current testing of heat-exchange tubes. The testing results can be used for preventative tube plugging. All the cases of massive corrosive damage of heat exchange tubes refer to SGs that had been in long-term continuous operation without chemical washing and proper observance of water chemistry standards.

Currently, the most common form of failure is stress-corrosion cracking and this now accounts for 60 to 80 percent of tube imperfections demanding plugging.

Fretting (wearing of tubes in their supports due to flow induced vibration) and pitting (breakdown in the protective film on the tube) combine to account for 15 to 20 percent of defects in tubes. The remaining percentage of degradation are attributed to mechanical damage, denting, and fatigue cracking. The problems related with the steam generator were thought to be isolated occurrences from defects in manufacturing, poor operations, poor water chemistry and others. As time passed, however, a pattern of failures began to emerge that suggests mutual factors and common degradation modes. In a nuclear plant operation, there are some contamination which emerge from fission products, trans uranium elements from fuel rod cladding insulation that generate some particular conditions for steam generators management, inspection, cleaning, maintenance, and decommissioning. During operating mode, some safety measures must be considered in order to avoid occurrence of accidents making an example, in the case of excessive carryover, correction should be made instantly or else it will lead to permanent damage to the turbine. This instance can be caused by either a high-water level or a high concentration of solids in the boiling water and it can be corrected by either lowering the water level or blowing down. The water level must be observed intermittently, as well as temperature control to the steam side and the maximum heating or cooling rate to the primary coolant, all in accordance with the specific plant operating directives. There are a number of material degradations for primary side SG which occurs and they are listed below [24]:

a. Stress corrosion cracking and intergranular attack (the boundaries of crystallites of the material are more prone to corrosion than their insides);

b. Degradation of primary header divider plates;

c. SG tube magnetite build-up (it leads to depreciation of thermal efficiency, and likely safety related impact on inspection capabilities);

d. Tube plugs.

Water lancing is a common SG cleaning technique which is done routinely at many plants and it involves directing a high-pressure water jet between the tubes from the (central) tube-free lane. The jet oscillates in a vertical plane. It involves access through the shell and the down comer shroud.

Foreign materials also known as debris that have been identified includes Welding electrodes, Wire, Screws and Gasket material. Some materials may be left behind during construction and that can add up to the debris. It is known that degradation of the heat-exchange tubes in the steam generators in nuclear power plants with WWER reactors arises during operation for the following reasons.

a. breakdown of the water-chemistry regime.
b. ill-timed chemical laving.
c. corrosion of the heat-exchange tubes in downtime regimes.

The existence of copper-containing materials in the second loop, which, in the first place, makes it impossible to increase the pH of the feed water above 9.2 in order to lessen the amount of corrosion of iron entering from the second loop to a minimum level. The second reason being that it results in deposits on the heat-exchange surfaces of the steam generators. Together with iron compounds, a considerable quantity of copper and its compounds forms corrosion. The imperfections which result in degradation of heat-exchange tubes include pitting, corrosion pits, and cracks of different depth and length, right up to through cracks [24].

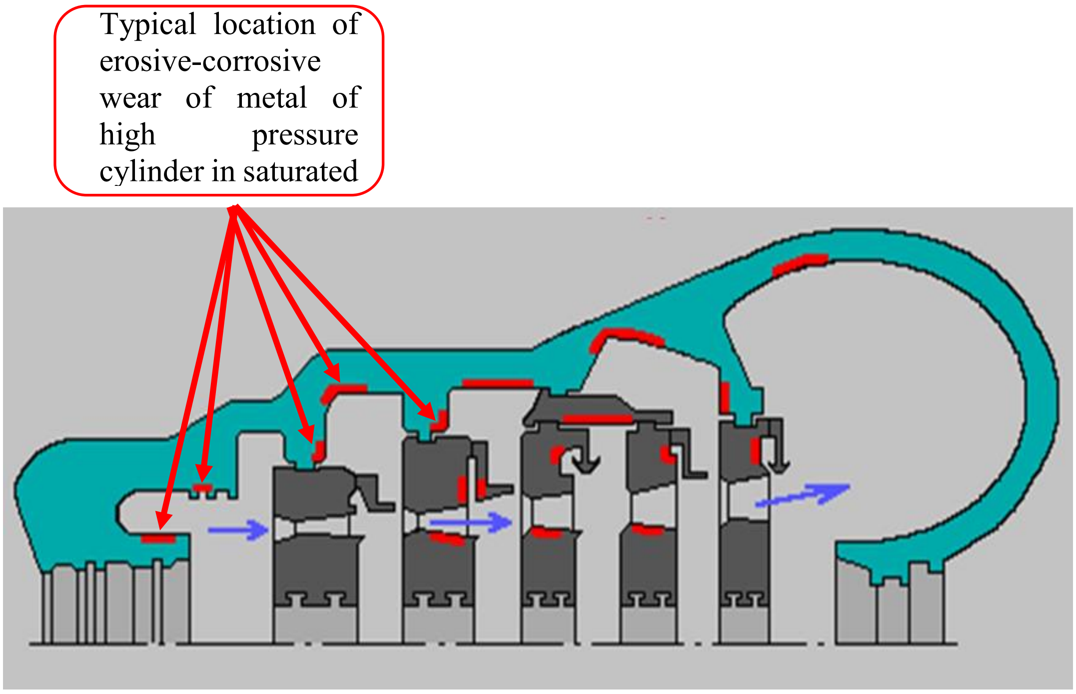

Figure 1.17 - Describes corrosive parts of the steam generator

1.5.1 Decontamination and decommissioning of steam generator

When nuclear power plants approach the end of its lifespan, decontamination and decommissioning of Steam Generators must be planned. It demands a strategic and scientific measurement to be taken. This also includes the assessment of environmental, legislation and economic issues. Decontamination implies the removal of contamination from surfaces of facilities or equipment. This can be achieved by washing, heating, chemical or electrochemical action and mechanical cleaning. Decontamination is done to decrease radiation exposure, reduce the amount of equipment or materials that requires radioactive waste management and decrease the magnitude of the residual radioactive source. Steam Generators are one of the metal intensive components in decommissioning nuclear power plants and due to this their material should be managed with an attitude of reuse, recycling and clearance of all material and scrap [25].

Clearance is a stage that requires radionuclides concentrations to go low for it to be considered no longer considered a radioactive hazard. Issues concerning the release of these material are not internationally consistent, but in all cases, it has to conform with radiation protection principles. Clearance levels are endorsed by the European Commission and other international organizations. The clearance is capital intensive but in the long-term clearance is the best waste management choice internationally recognized.

1.6 Steam generator regulatory framework

In as much as the steam generator is an import ant part of the nuclear power setup and it construction has to be carefully done, it is also important to have regulations to manage everything that comes with it. The Nuclear Energy Institute (NEI) of the United States harmonized efforts to improve both the quality and reliability of steam generator programs in the year 1997 which led to all U.S. PWRs adopting NEI 97-06, "Steam Generator Program Guidelines." A new steam generator requirement was put in place that the NRC approved in 2005 by specialists. The NRC later discussed the new requirements and plant implementation of NEI 97-06 in Generic Letter 2006-01. As a result of this, all U.S. PWRs adhered to the letter by implementing the task force requirements [26]. Some issues pertaining to the requirements has since been clarified in other maintain standards that has been set and also from the plants' experience learned with those requirements. A task force is in place to revise both inspection schedules and the ways plants select tubes for inspection which are documented. The revision's editorial corrections, changes, and clarifications better associated with other industry management documents. The NRC accepted these extra revisions in October 2011 and many United States plants have improved their technical specifications accordingly.

1.7 Hydrodynamic issues of nuclear power plant (NPP) steam generators

Service reliability of NPP steam generators is associated in many respects with hydrodynamic processes of coolants and working fluids. All steam generators (SGs) exploit the movement of fluids or gases in the transport and transfer heat energy from the coolant to the working fluid of the steam generator. Hydrodynamic processes determine the level and stability of the temperature pattern in the assembly parts of SGs. These processes also form the basis of vibration, erosive damage and force impact on the construction elements of SGs just to mention a few. The advances made in nuclear power industry is not possible without an in-depth study of hydrodynamics and heat transfer processes. In the interim, the most important is the examination into various parameters with regard to steam-water mixture which is used.

Enhancement of efficiency and reliability of power equipment requires increased calculation accuracy. On the one hand, the intensity of heat transfer in a SG is determined by a heat surface geometry, thermal and physical properties of a substance at the set parameters, and especially by the hydrodynamics of the flow. On the other hand, the hydrodynamic processes determine the efficiency of a SG since the heat transfer efficiency and the power input required for circulation are reliant on the organization of coolants' movement. Hydraulic calculation along with thermal calculation are the primary calculations when designing a steam generator.

1.8 Inspections and cleaning of tube in steam generators

The steam generators used for commercial purposes normally sees dependability problems within the first decade of operation which is associated with material degradation even though many measures are kept in place to keep them safe. Some main causes of these degradation are particle deposition and tube fouling. As a result, steam generators often involve high cost expenses for inspection and cleaning of fouling deposits [27]. In-service inspections are very necessary in maintaining the integrity of steam generator tubes. The possibility and frequency of these inspections vary from plant to plant based on each facility's operating data gathered from experience. The drive for inspection is to determine the condition of the system and to locate any defects which may require repairs. The system including separator, purifier, piping and drains may require servicing such as the inspection on all internal surfaces for corrosion or erosion and note rare conditions which is vital. Abnormalities are often indicated by the presence of scale, grit, or other foreign materials found in the system. Access to the inside of the primary channel may be achieved by some steps; Prior to conducting any test or check, the area around the steam generator should be carefully monitored to determine the amount of radiation in the area. People working on the steam generator and radiation field must be measured for radiation dose and well controlled as it's a requirement of every nuclear power station. Apart from inspection purpose, other repair work that is of high concern is the plug leaking tubes. The thickness of the tubes can be measured during plant operation, so as to insulate those tubes which are affected by corrosion and this insulation involves welding plugs on both sides of the U-tube. Tubing inspection requirements vary slightly in these and other countries because:

1. Different steam generator designs, materials and specific sites are vulnerable to different forms of ageing deterioration. Some of deterioration forms are

easier to detect or give rise to less severe safety consequences than other forms of degradation.

2. A suitable level of steam generator and plant safety can only be sustained by an appropriate combination of inspection and acceptance (fitness-for-service) requirements. Countries have agreed to apply meaningful conservative fitness-for-service criteria and less inspection. Other countries also choose less conservative fitness-for service criteria (helps to save money on repairs) and more inspection. The rate and scope of the inspections normally increase as problems develop.

1.8.1 Tubing inspection requirements in Russia

Russian steam generator tube checkups are performed when leakage of the primary coolant into the secondary coolant system is noticed. The tubes are inspected with the use of "visual and hydro-luminescent" methods. During the process of testing the secondary side is drained and pressurized with gas and video cameras are positioned inside the collectors to check out for bubbles. Other method of inspection the use of a fluorescent substance that is added to the secondary water which is pressurized. The primary side is drained while the tube ends are inspected. Eddy current inspection is being familiarized at some Russian nuclear power plants now and Primary-to-secondary leak rates are observed using a Na device.

1.8.2 Germany tube inspection

In the Federal Republic of Germany, the scope and frequency of tubing inspections in the steam generator are specified in KTA 3201.4. Ten per cent of the tubes in each steam generator are to be fully checked every four years and half the steam generators must be checked every two years. However, definite inspections have been more regular and some Siemens steam generators have been inspected every operating period over much of their life.

1.8.3 Tubing inspection requirements in the United States

The necessities for the steam generator tube inspections for plants located in the United States forms part of the Technical Specifications, which are provided by the plant operator and approved by the USNRC. Officially, those requirements generally follow the procedures presented in the USNRC's Regulatory Guide 1.83 in the year 1975. These guidelines are planned according to the following; access, equipment and procedures, baseline inspection, sample selection, supplementary sampling, inspection intervals, acceptance limits, and corrective measures. In summary, the steam generator should be planned with satisfactory access to make inspection and plugging more comfortable. Eddy-current or equivalent equipment that is very sensitive to detect failures or imperfections up to 20% or more through the tube wall are to be used. An overall inspection of all tubes should be completed prior to service and after any major secondary side water chemistry change.

Regulatory Guide 1.83 endorses that at least 3% of the tubes in every steam generator should be tested over their entire length during the first inspection and this should be performed after six months effective full power operation but before 24 calendar months. Succeeding inspections is normally done in not be less than 12 or more than 24 months apart and this is limited to 3% of the total tubes at the plant per every steam generator. The tubes which were not plugged previously giving indications (>20%) should be inspected. Any new signs of degradation found (>20%) or if previous indications exhibit growth (>10%) the rest of the steam generators should be inspected. If two successive examinations result in less than 10% of the inspected tubes with indications (>20%) and no further penetration of previous indications, the number of times for checking of the tube should be increased to 40-month intervals. Impromptu inspections are done in an instance of primary-to-secondary coolant system leaks exceeding the technical specifications or during various design basis accidents (seismic, loss of coolant, main steam or feedwater line breaks).

1.8.4 Tubing Inspection Requirements in Canada

The Canadian Standards for tubes, CAN/CSA N 285.4-94, necessitates that an inspection of 25% of the tubes in each steam generator be conducted after the steam generator is first installed, but prior to service [28]. The primary in-service inspection and frequency is 10% of the tubes in each steam generator unit in an interval of 5 years. The inspection boundaries are increased if significant degradation is detected. The additional inspection takes into account tubes surrounding those with indications and do not comply with the acceptance criteria to bound the degradation. The minimum requirement for the additional inspection to be carried out is when all tubes whose center lines are located within a radius of 2.5 times the tube spacing from center line of affected tube. The Canadian Standard is somewhat imprecise about the numbers of common tubes located in other steam generators that need to be examined. The Canadian regulatory authorities thus expect the developers of the designs to consider specific proposals and submit them for unit restart. This makes the owners of the steam generators to bear the primary responsibility for the safety and good performance of the reactors. The Canadian Standard necessitates that alternative NDE techniques be used to detect flaws not readily detected by the standard bobbin coil eddy current inspection technique. Apart from ultrasonic, visual and profilometry inspection techniques that is being used where appropriate, a suitable alternative NDE techniques involves the use of special eddy current probes such as the transmit-receive Cecco probes and motorized rotating pancake coil probes. The decision of using an alternate inspection method depends on the type of degradation encountered and where it is positioned.

Their standard makes provision for a section of one tube to be removed from one steam generator for metallurgical inspection once in every five years and this applies to the lead unit in a multi-unit station. The results of these periodic destructive inspections are used to standardize the non-distinctive test techniques. In real life of operating a power plant, the plant operators usually go beyond these requirements and prepare specific programs of inspection and assessment appropriate to the individual sites. Even a new station goes beyond these requirements in both extent and frequency. Giving an example, Darlington is a four-unit power station but it necessitates a tube to be removed from one steam generator in each unit every two years. Also, the minimum inspection sample is 20% (instead of 10%) of one steam generator. Here, ultrasonic and specialized eddy current probes are normally used, not just bobbin coil probes.

Cleaning the steam generator involves the removal of slag, grease, paint or any other foreign materials when present. It is significant to remove all organic materials since they would decompose and contaminate. Removing all particles of dust from heated surfaces must be extended at least to all heated surfaces. Various chemical and mechanical methods are used in this process (chemical methods, vapor cleaning, brushing). One or more of these methods are used to maintain safety.

1.9 Steam generator inspection techniques

1.9.1 Visual Inspection and Measuring Testing

Visual inspection (VI) is a control testing performed by the visual organs that perceive the radiation of an object in the visible spectrum. Given the wide variety of surface flaws that may be detectable by visual examination, the use of visual inspection can encompass different techniques, depending on the product and the type of surface flaw being monitored. Imperfections of materials and structures which are large enough for the naked eye are conducted by visual inspection. External visual inspection of material used in steam generator productions in search of theoretical defects is done with the help of visual optical instruments (lenses, magnifiers, microscopes, endoscopes, radial patterns, measuring probes, angular and depth gauges) and without them. The essential deficiency of visual inspection is characterized by the restriction of the study of only the visible region of the object. Thus, VI in practice is combined with other methods of NDT and technical diagnostics (TD) very often.

Table 1.2 - advantages and disadvantages of visual testing

Advantages of VI	Disadvantages of VI
1. The most rapid method of testing. 2. It does not require large material costs. 3. Clear and easy to use. 4. Control of any materials.	1. It allows to detect only surface defects. 2. It is possible to miss microscopic defects.

Figure 1.18 – Shows visual inspection and tools used.

1.9.2 Liquid penetrant testing (LPT)

This is a method of defectoscopy which works on the principle of penetration of certain contrast substances into the surface defective layers of a steam generator under the action of capillary (atmospheric) pressure. Subsequent processing by a developer, the light or color contrast of the defective area relatively to the undamaged will show.

Figure 1.19 – Shows material for capillary testing.

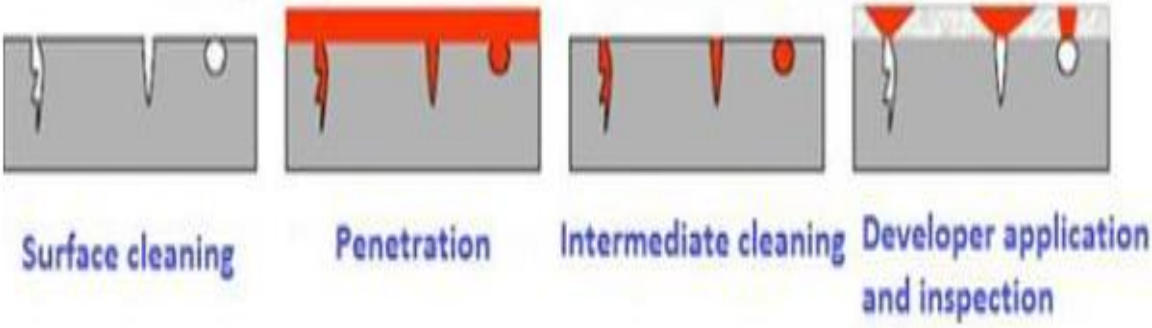

Figure 1.20 – Shows sequence of operation in capillary testing.

According to technical requirements or conditions nuclear power plant components, it is necessary to detect very small defects (up to hundredths of a millimeter) and it is simply impossible to recognize them with a normal visual inspection of the naked eye. Sensitivity used in capillary testing is the ability to detect discontinuities of a given size with a given probability when using a particular method, control technology and penetrant system. According to Russian State Standard 18442-80 the sensitivity control class is determined depending on the minimum size of the detected defects with transverse dimensions of 0.1 - 500 µm. Detection of surface imperfections having an opening size of more than 500 µm, tells that capillary testing methods is not guaranteed.

Table 1.3 - Advantages and disadvantages of capillary testing.

Advantages of LPT:	Disadvantages of LPT:
1. Control of any (ferromagnetic and non-magnetic) materials; 2. High sensitivity and control resolution; 3. It does not require large material costs; 4. Visibility of inspection results; 5. Efficiency (control of wide parts of parts or welded joints at a time).	1. It allows to detect only surface defects; 2. High requirements for surface preparation; 3. Harmfulness of some controls (use of protective devices and ventilation); 4. Limited shelf life of materials, the dependence of their properties on storage time and ambient temperature.

1.9.3 Ultrasonic testing

Ultrasonic testing is a volumetric nondestructive method employed usually for in-operation review of components. Ultrasonic methods of testing are able to detect pits and circumferential cracks in the existence of axial cracks which often develops in tubes. Some WWER units employ an automated ultrasonic system which is helps to detect shallow tube pits. This is due to the fact that the system uses high frequency ultrasonic (50-100 MHZ) and has high rate of research at low cost and less hazardous to humans (in comparison with X-ray flaw detection) with good mobility of the ultrasonic flaw detector. Notwithstanding these pluses, it is practically impossible to produce reliable ultrasonic testing of coarse-grained structure metals, such as cast iron or austenitic weld (over 60 mm thick) due to large scattering and strong attenuation of ultrasound. There is a need to ensure good contact with the surface of the control object hence glycerin is used. A type of equipment used in ultrasonic testing is shown with its transducer in the figure 1.21 below.

Figure 1.21 – Shows equipment used for Ultrasonic testing.

1.9.4 Eddy current testing

Much dependence is placed on eddy current testing because this technology works very well on tubes with thin-wall of all sort used in WWER (PWR) and CANDU steam generators due to the large number of tubes to be inspected. Eddy current array (ECA) is a nondestructive testing technology which provides the opportunity to electronically drive multiple eddy current coils, which are positioned side by side in the same probe assembly [29]. The eddy current testing method is founded on the analysis of the interaction of an external electromagnetic field with the electromagnetic field of eddy currents induced by a pumping coil in an electrically conductive controlled object (CO) by this field. An inductive coil (one or more), called the eddy current transducer (ECT) is most often used as the electromagnetic field source. It allows to detect surface and subsurface defects with high repeatability of test results. Eddy current testing is not affected by moisture, pressure, surface contamination with non-conductive substances. The undesirable issues of eddy current testing are that depth of control (penetration of currents) does not exceed 6 mm and being able to detect ferromagnetic materials. Additionally, the cost of systems and means of control is quite expansive.

Figure 1.22 – Shows equipment used for eddy current testing.

1.9.5 Radiation testing (Radiographic Testing)

Radiographic testing (RT) is characterized by the interaction of penetrating ionizing radiation (X-ray, neutron flux, γ- and β-rays), with a controlled object and transforming the generated radiation image of controlled object onto a memory device (radiographic film).

RT is used to test or regulate the quality of welded and soldered joints, castings, quality of assembly work, the state of closed cavities of aggregates, etc. Penetrating radiation passing through the thickness of the controlled material and interacting with its atoms, conveys various information about the internal structure of the substance and the existence of hidden defects within the controlled objects. The most common radiation methods are radiography, radioscopy and gamma-control, which have found application at the enterprises of metallurgy and machine building. As sources of penetrating radiation, X-ray machines, linear accelerators, gamma-ray flaw detectors, etc. are used.

Table 1.4 - Advantages and disadvantages of radiographic testing.

RT Advantages	**RT Disadvantages**
- it allows to detect surface, subsurface and internal defects;	- the most dangerous of the NDT methods;

- high informative test; - high repeatability of test results.	- expensive consumables (controls); - it does not detect defects in fillet welds; - it does not reveal the exact depth of defects.

1.9.6 Leak detection (Leakage Monitoring)

The method of control by leak detection refers to the type of non-destructive quality control by penetrating substances along with the liquid penetrant testing. Leak detection is one of the most effective and important approaches of detecting through defects in vessels, closed volumes, and also welded seams. As the concept of tightness is the main operational prerequisite for many products, inspecting equipment for lack of leaks is an important and responsible process. Exclusively high requirements are imposed on products operating under vacuum and high pressure.

Examination the tightness of structures and their components is carried out in order to identify leaks caused by the existence of through cracks, fissures, burns, etc. in welded joints and metallic materials. The leak testing is characterized by the use of test materials and recording their penetration through leaks in the structure with the help of various devices such as leak detectors and other means of the test substance registration. Tightness is the property of the product to limit the penetration of liquid or gas through the elements of the structures and their connections.

Figure 1.23 – Shows equipment used for leakage testing.

Table 1.5 - Advantages and disadvantages of leakage testing.

Leakage Monitoring Advantages	Leakage Monitoring Disadvantages
- the possibility of detecting microscopic defects; - testing of large-sized objects (products).	- it is designed to detect only through defects; - high requirements for surface preparation; - great control time; - the danger of certain controls (gases and liquids); - the difficulty of recycling some of the controls used.

1.9.7 Destructive testing

All other forms of tube testing (Eddy current inspection and ultrasonic examination) techniques can be qualified by removing previously examined tubes from an operating steam generator and examining the flaw indications in a laboratory. Suitable destructive examinations which is often called "pulled tubes" does not only quantify the fault indications but also provide substantial information about the extent degradation mechanisms. In the destructive testing pulled tubes can be used to determine as to if the secondary-side corrosion defects are acidic and goes further to detect species connected with the chemical attack. Pulled tubes also helps to regulate leak rates and burst pressures, by giving information which is beneficial for assessing tube integrity. Additionally, inspection of pulled tubes gives an opportunity to look for any emerging issues.

This form of metal testing causes deformation to the controlled object and is an integral process to establishing how a tested material performs under exacting conditions and whether it complies with national or international standards. Manufacturers, metal stockholders, importers and welding inspectors need the assurance that a metal or alloy will be suitable for a product’s intended use or meets industry specifications in order to avoid accidents and economic loses. This gives you a fare idea of the material which is best for your production work.

Impact testing

Impact testing measures the material's ability to absorb energy when fractured at high velocity. This gives an indication of the 'toughness' of the metal.

Tensile testing

Tensile testing, or tension testing, is used to determine the behavior of the metal when it is being pulled. Tensile testing can measure yield strength, proof strength and ultimate tensile strength. We have a range of tensile testing machines and can apply loads from a few newtons to 1,000 kilo newtons, and test up to 600°c.

Hardness testing

Hardness testing assesses the impact of the metal or alloy to permanent indentation, and the depth or size of the indent is measured to determine a hardness value. There are several different hardness tests and we use the Brinell, Vickers and Rockwell methods.

3 Comparative analysis of steam generating path in the WWER units

3.1 The quality of steam required in the steam generator of the WWER designs

The criterion for the quality of the generated steam is the separation characteristic, which is the dependence of steam humidity, the height of the steam region between the evaporation surface and the lower edge of the vapor perforated sheet.

Representations of parameters through graphs

The parameters of the Russian WWER-1200 was used to calculate the moisture separation of the steam generators in order to observe their behavior including plotting graphs with PTC Mathcad to finally validate the theoretical formulas produced in this dissertation. The aim of this calculation is to determine the superficial velocity with which steam passing through the disengagement surface moves with, actual water level in the operating steam generator and moisture content at the entry of the louvre separator or steam outlet pipes. The parameters of WWER-1200 used in the calculation is shown in the appendix as Table 3.1.

Superficial velocity:

The superficial velocity was observed to vary linearly with the steam mass flow rate at constant density of the fluid and constant heated area.

The superficial steam velocity on the evaporation surface reached a value of about 0.43 m/s at maximum power for the WWER 1000 project [30]. According to the equation (2.8) it was calculated to be 0.34 m/s for the WWER 1200 design.

$$w_0^{''}(D) = 0.0005237D, \qquad (3.1)$$

Where, D =120, 121,.. 600

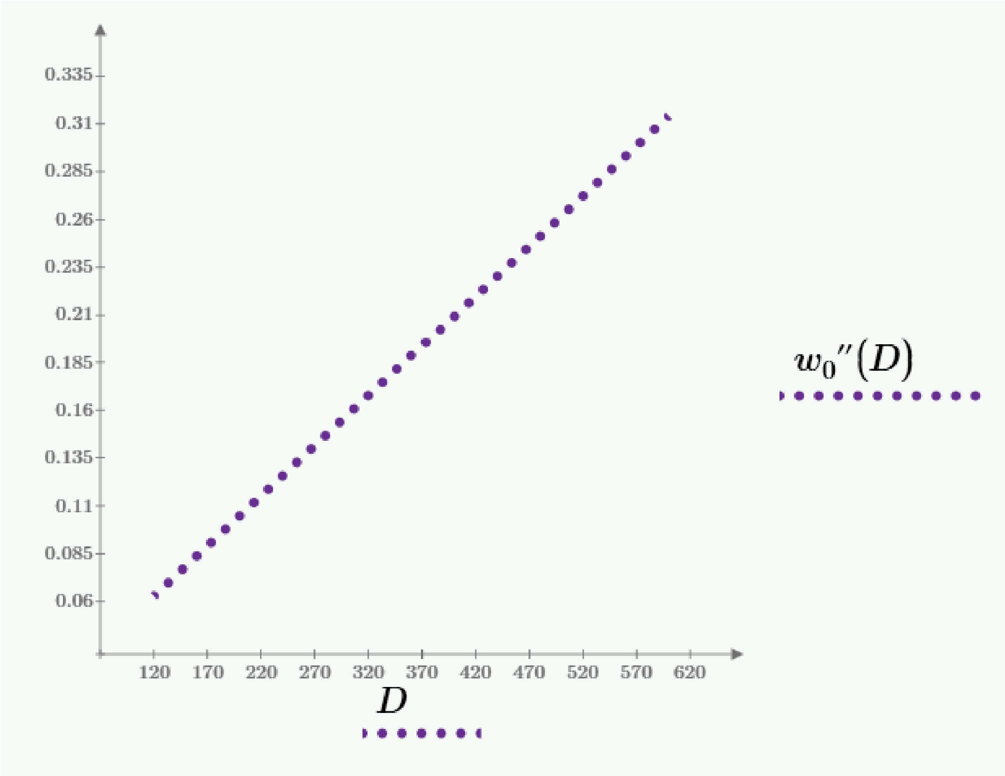

Figure 3.1 – Illustrate the graph of superficial velocity against flow rate

Actual water level in steam generator:

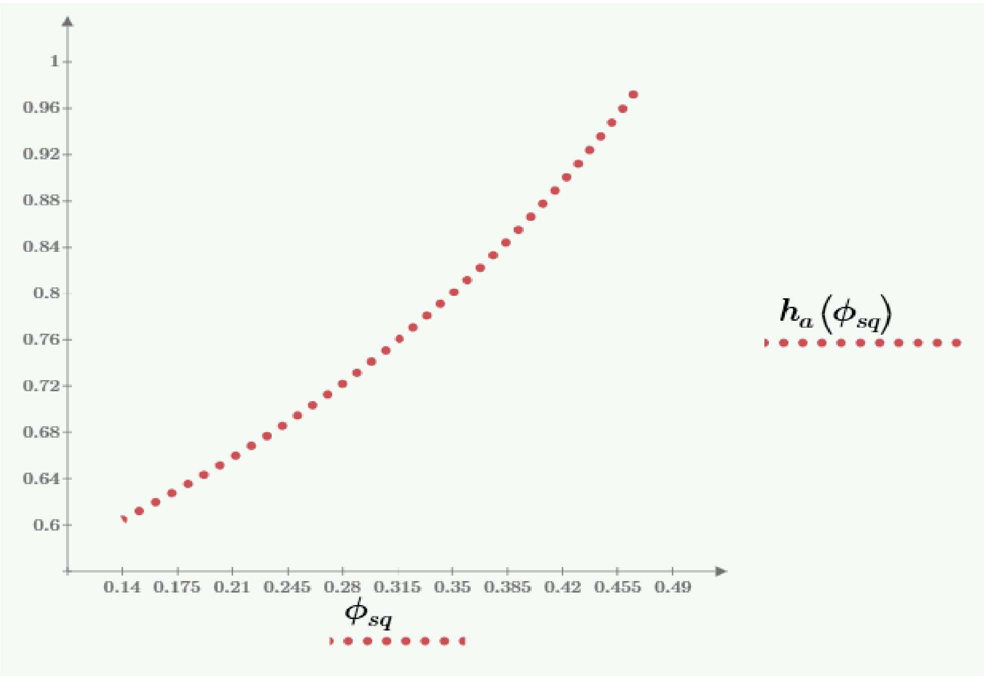

Figure 3.2 – Illustrate the graph of steam quality against actual height

$$h_a(\emptyset_{sq}) = \frac{0.52}{1-\emptyset_{sq}}, \tag{3.2}$$

where, $\emptyset_{sq} = 0.14, 0.15, \ldots .0.47$

In calculation and graphical representation, it was observed that, the volumetric steam quality in the steam generator depends on the superficial velocity though the dependence is not linear. As the volumetric steam quality increases, the superficial velocity also increases but not at the same rate. Hence the actual water level in the steam generator depends on the actual volumetric steam quality. The better the steam quality produced by the louvre separator, the higher the water level. The lower the steam quality, the lower the water level due to the fact that more moisture will be carried by the steam into the turbine unit.

Steam velocity at the louvre separator entry

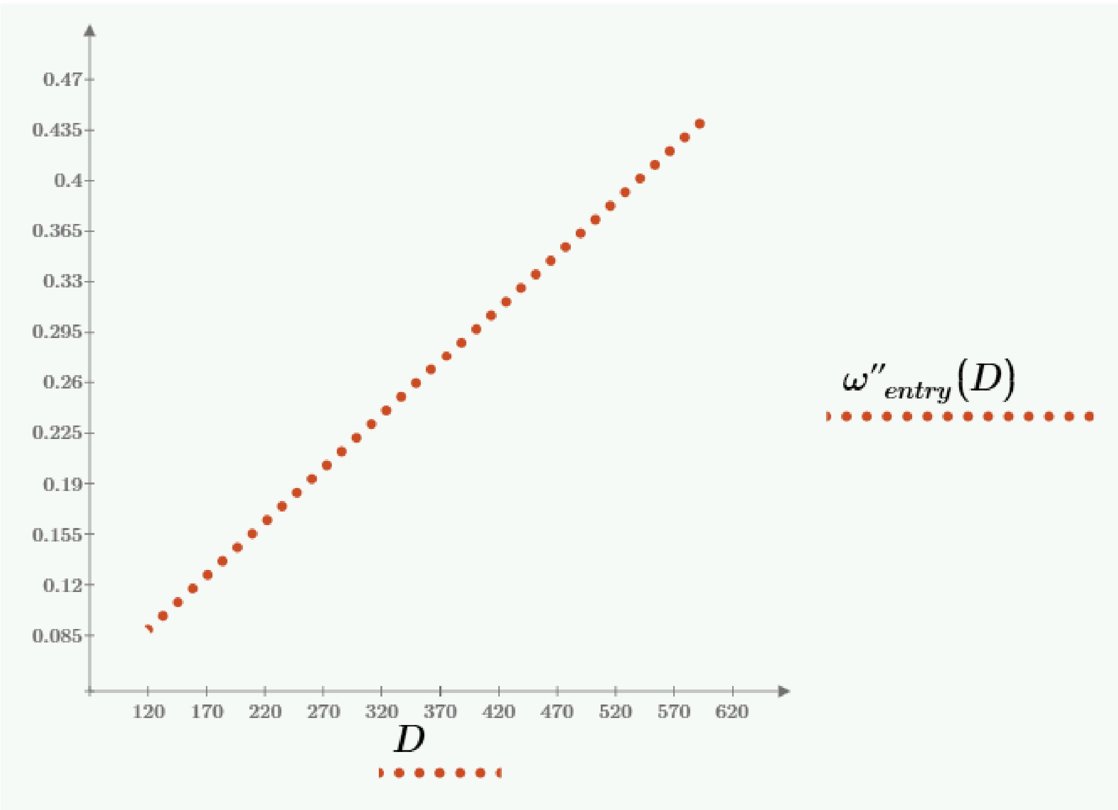

Figure 3.3 – Illustrate the graph of velocity at the louvre entry against flow rate

$$w''_{entry}(D) = 0.00074266D. \quad (3.3)$$

Similar to the superficial velocity calculations, the velocity at the entrance of the louvre separator is directly proportional to the steam mass flow rate, even though the velocity at the entry is usually higher than the superficial velocity. According to the formula, the velocity at the louvre entry for WWER 1200 was calculated to be 0.316 m/s. This is due to the fact that, at the entry of the louvre separator, the steam is much higher than when it was at the disengagement surface. At that point the steam has lost most of the moisture due to gravity.

Moisture content of the steam at the entrance of the louvre separator

From the calculation, the moisture content at the entry of the louvre separator in a WWER 1200 steam generator plant is about 0.0216% comparing to the maximum permissible value of a louvre separator which is about 2%, it implies that the theoretical formulation is valid and it eventually increases the safety of operation of the second circuit of NPP due to the increase in the allowable range of changes in the level of the boiling water.

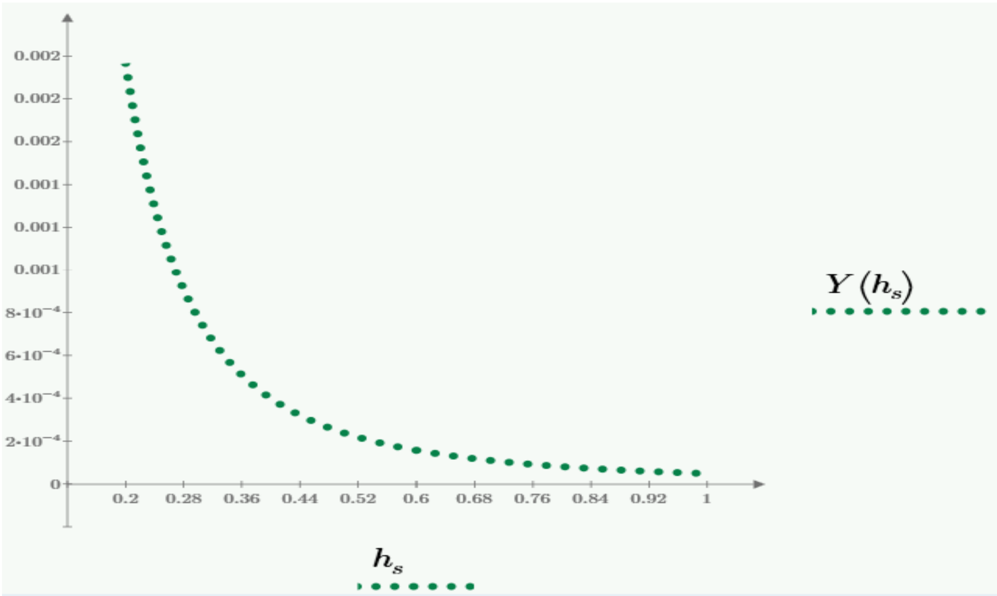

Figure 3.4–illustrate the graph of moisture against height of steam region.

$$Y(h_s) = 2.58 \cdot 10^{-3} \frac{(0.237)^{2.76}}{(h_s)^{2.3}} \quad (3.4)$$

$$h_s = 0.2, 0.21, \dots 1.0$$

The height of the steam region in the WWER 1200 was calculated to be 520mm using the equation (2.9). The separation characteristic determined experimentally for industrial separation of moisture which was carried out for one of the Rostov Nuclear power plant SGs is shown in figure 3.5. The arrow shows the nominal level 2400mm of the evaporation surface from the bottom SG point.

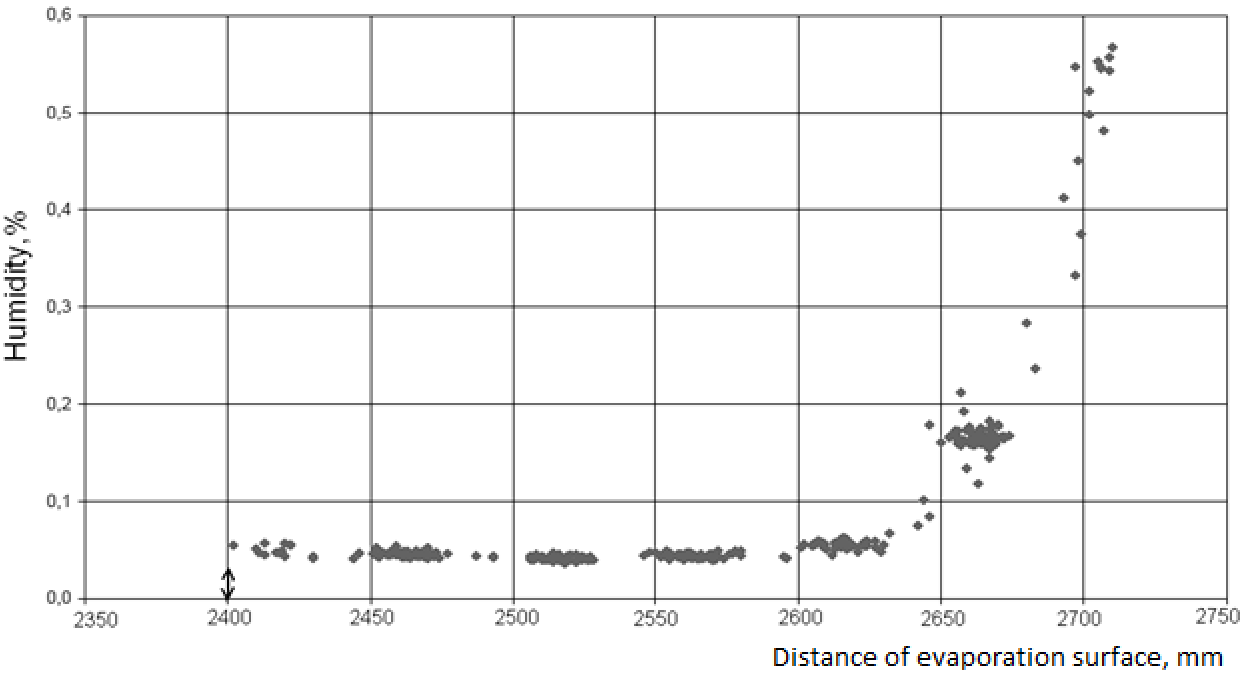

Figure 3.5 - Separation characteristic 1PGV-1 of Rostov NPP [31]

The first ascending section of the separation characteristic is fixed at rise of the evaporation surface from 2600 to 2650 mm. The steam humidity at the outlet from the SG did not exceed the permissible value of 0.2% and was in the range of 0.16÷0.18%, when reaching the level of 2650 mm. When the level rises from 2650 to 2700 mm steam humidity increased from 0.18 to 0.57% and went beyond the permissible value. According to the standards, moisture content of steam at the entry of louvre separator should not be more than 4…5 %. The calculated value of moisture content for the WWER 1200 with a louvre separator was $2.16*10^{-4}$ %. This agrees with the plotted graph in figure 3.5 taking from a real nuclear power station hence making the formulas produced in this work valid.

Increasing the heating capacity of the steam generator PGV-1000MKP to 800 MW in steam capacity 1600 t/h in the V-392M (WWER-1200) project may require further improvement of the separation scheme since other properties like pressure and height of steam region may increase.

To reduce the local velocity of the output steam from the evaporation surface and reducing steam humidity at the outlet of the steam line, SG worked and implemented submerged perforated sheet with variable degree of perforation. This will reduce the uneven load of the evaporation surface on the horizontal section of SG.

4 Financial management, resource efficiency and resource conservation

4.1 Financial management

The projections made into scientific researches are not only determined by the scale of the discovery and resource-efficient product, but also it can be seen as a commercial value of development. Evaluation of the commercial potential of development is a prerequisite in the search for sources of funding for scientific research and commercialization of its results. This is of great significance as developers needs represent the state and prospects of ongoing research. The commercial attractiveness of scientific research is determined not only by exceeding technical parameters over previous developments, but also how quickly the developer will be able to find answers to such questions as whether the product will be in demand by the market, how much will it cost that will be reasonable to the customers, what is the budget of the scientific project, etc.

The purpose of this section is to design and create Competitive developments and technologies that meet the requirements of requirements in the field of resource efficiency and resource saving. Achievement of the goal is provided by solving problems:

1. development of the overall economic idea of the project, the formation of project concept;
2. organization of works on the research project;
3. identification of possible alternatives to scientific research;
4. planning of research works;
5. assessment of commercial potential and prospects of holding research from the standpoint of resource efficiency and resource saving;
6. definition of resource (resource-saving), financial, budgetary, social and economic effectiveness of the study.

The section of financial management in this dissertation consist of two main aspect. The first aspect discusses cost of different steam generators used in the nuclear industry and cost of replacing a steam generator. Its resource efficiency and consolidated energy investment. The second includes a budgetary report of the scientific project. The cost evaluation was performed for competitiveness of horizontal steam generators with louvre separators based on SWOT Analysis.

4.2 Potential consumers of research results

The outcome of the study has the potentials of producing significant savings in the production of nuclear energy, increasing production without the construction of additional power units and ultimately it does not reduce the indicators of nuclear and radiation safety. The target market for this study will be state-owned nuclear power corporations, nuclear and related industries of the Russian scientific industry. This section shows how specific models of steam generating plants can be relative to the level of performance requirements and marketing services.

		Steam generator models		
		PGV-440	PGV-1000	PGV-1200
Level of performance requirements	Unsatisfactory			
	Satisfactory			
	High			

Figure 4.1 - Map of the segmentation of the services market relative to the level fulfillment of operational requirements of PGV

4.2.1 Analysis of competitive technical solutions

For the analysis of competitive technical solutions, the above models of steam-producing plants; PGV-440 and PGV-1000 are considered. Position development and competitors is estimated for each indicator expert by a five-point scale, where 1 - the weakest position, and 5 - the strongest. The weights of the indicators, determined by an expert way. Analysis of competitive technical solutions is determined by the formula:

$$C = \sum_{i=1}^{n} CW_i * P_i \ , \qquad (4.1)$$

where C - the competitiveness of scientific developments or competitor;

CW_i - weight index (expressed as a decimal);

P_i - expert points. *i-th* index.

Table 4.1 - Evaluation map for comparing competitive technical solutions (developments)

Evaluation criteria	**Criteria Weight CW**	**Points (P)**			**Score=CW*P**		
		P	P_1	P_2	S_0	S_1	S_2
1	2	3	4	5	6	7	8
Performance resource evaluation criteria							
1. Increasing user productivity	0.1	5	4	4	0.5	0.4	0.4
2. Ease of operation (corresponding to the requirements of consumers)	0.1	5	4	3	0.5	0.4	0.3
3. Energy Efficiency	0.06	5	4	3	0.3	0.24	0.18
4. Reliability	0.06	5	4	4	0.3	0.24	0.24
5. Noise	0.01	5	5	5	0.05	0.05	0.05
6. Safety	0.06	5	5	5	0.3	0.3	0.3
7. The demand for material resources	0.03	4	4	4	0.12	0.12	0.12
8. Functional capacity (possibility provided)	0.06	5	4	3	0.3	0.24	0.18
9. Interferences	0.04	5	5	5	0.2	0.2	0.2
10. Ease of use	0.1	4	4	4	0.4	0.4	0.4
economic criteria for evaluating the 5effectiveness of							
1. The product competitiveness	0.03	5	4	4	0.15	0.12	0.12
2. Price	0.05	5	4	3	0.25	0.2	0.15
3. Estimated useful life	0.2	5	4	4	1	0.8	0.8
4. After-sales service	0.05	5	5	5	0.25	0.25	0.25
5. Financing scientific development	0.05	5	4	4	0.25	0.2	0.2
Total	**1**				**4.87**	**4.16**	**3.89**

Based on the analysis presented above, it can be concluded that the steam-producing plant studied in this thesis is the most suitable for operation in specified modes. Competitive installations do not sufficiently satisfy the established operating modes, due to the outdated design.

4.2.2 Cost structure of operating SG at a nuclear power station.

The major concern of operating a nuclear power plants with wet steam turbines is the negative impact of moisture on economy and reliability of the turbine installation. This section will take a look at the cost involved for purchasing a new steam generator. In reality steam generators can replaced before the service lifetime of the whole reactor unit. The prices of steam generator continue to grow as the capacity and efficiencies also increase. These prices are mostly determined by agreements between the enterprise and the customer thereby making it difficult to get the actual price.

France in the year 2011 approved an order for 32 steam generators from Areva and 12 from Westinghouse. The orders are worth €1.1 billion ($1.5 billion) and €400 million ($545 million) to Areva and Westinghouse, respectively. From this price it can be estimated that the price on one steam generator cost approximately $47 million to $50 million. These steam generations are all to be installed at PWR designs with 1300 MWe and 900 MWe power. They are expected to have 60-year lifetime just as all existing reactors and after they can be replaced [34]. Other refurbishment, costing €400-600 million ($545-815 million) per unit to take them beyond 40 years.

TVA in the year 2014 as another scenario agreed to pay $160 million to Westinghouse to build four steam generators which be used to replace those in the Unit 2 reactor at the Watts Bar Nuclear Plant. Planning and installation of the new equipment is projected to cost nearly $200 million, bringing the total costs of the new equipment, installation and lost power for the Watts Bar steam generator project to more than $300 million [32].

Within 40 years after initial license of a reactor, there is a possibility of replacement of the steam generators for once. When about 15% of the tubes in the steam generator have been plugged, heat transfer properties depreciate such that replacement is desired for the plant to maintain maximum power production. An outage will need 35 to 60 days to replace steam generators. Considering the occupational radiation exposure inspection, maintenance, and power derating due to plugging among others, it may be economically feasible to replace steam generators.

An analysis made proved that, continuing with the existing SG equipment will not be economical. According to the analysis, installing a new steam generator would cut annual steam generator repair costs by $3.4 million as of the year 1996 [33].

4.2.3 Competitiveness of horizontal steam generators with louvre separators on SWOT Analysis

The SWOT analysis is a compact method to illustrate the results obtained by this study in a strategic way. The Strengths and Weaknesses of horizontal steam generators with louvre separators of the WWER designs are reported to internal factors evaluation. The Opportunities and the Threats are reported from external factors evaluation. Some collected strengths of considerable importance for the competitiveness and profitability of an investment. These opportunities are very relevant and although they cannot be quantified and valued, provides a strategic advantage that adds competitiveness to a possible production and usage of steam generators**.** The efficiency and competitiveness of steam generators was analysed comparing to other existing designs.

"Strength" are understood here as internal factor which positively impact the relative competitiveness of nuclear in the future.

1. The relevance of the selected topic is of great importance to the nuclear industry because it will lead to new and promising designs.
2. The horizontal steam generators with louvre separators helps to extend the life span of the steam generator. Accordingly, high humidity at the outlet from the steam generator leads to a decrease in the efficiency of the turbine, as well as to erosion of its first stages.
3. The existence of louvre separator adds to producing high efficiency of steam drying including gravitational separations employed by WWER designs;

4. The louvre separators provides high operation reliability to the steam generator and the turbine unit as a whole; the designing, manufacturing, and installation of louvre are quite simple and viable because the material for construction are readily available.

"Weakness" are understood here as internal factor which positively impact the relative competitiveness of nuclear in the future.

1. Lack of opportunity to verify all types of PGVs in specific operating modes and also to verify in long term of operation.

2. The louvre separator more weight to the steam generator because it is metal-intensiveness. This will add more to the cost of production of these steam generators. It comes along with additional cost in terms of maintenance and cleaning. More money will be spent to keep the steam generator properly working.

3. Complicated removal of separated water in order not to interfere with the evaporation surface because it can lead to reducing steam volume.

"Opportunities" are understood here as external factor which positively impact the relative competitiveness of nuclear in the future.

1. creation of new operating modes of steam generators which will perform more efficient than existing designs.

2. Opportunity and support for the development of nuclear energy through budgetary financing from the government and individuals to support science works especially in the field of nuclear has led to improve power generation in the world.

3. Additional demand for research results which has been done on methods of improving the performance of SGs.

4. Social benefits of nuclear power include direct employment and positive impacts of stable and predictable cost of electricity on the economy.

"Threat" here are understood as the external factors that could threaten or negatively impact the relative competitiveness of nuclear in the future.

1. The possibility of damage and subsequent failure the steam installation such as non-uniform boiling and poor steam quality. The quality of steam significantly affects the relative internal efficiency, stages of the turbine and, accordingly, the relative internal

efficiency of the entire turbines. In connection with a decrease in the humidity of the steam at the inlet to the turbine,

2. The likelihood of having similar developments from the competing party including designs from nuclear oriented countries.

3. Delivery of project financing which is normally done by the state since it involves a lot of money and also nuclear facilities being owned by the state. This is of major concern especially in developing countries aiming to use nuclear energy as a source of power generation.

4. Uncertainties in the construction cost i.e. increase in construction and raw material cost as the economics of the world keeps varying.

Table 4.2 - Interactive matrix of the strength to opportunities in the project

Strengths of the project					
Project Opportunities		S1	S2	S3	S4
	O1	+	-	+	-
	O2	+	-	0	0
	O3	-	+	-	-
	O4	-	-	0	0

Table 4.2 - Interactive matrix of the strength to threats in the project

Strengths of the project					
Project Threats		S1	S2	S3	S4
	T1	-	+	+	-
	T2	-	-	-	+
	T3	+	-	-	-
	T4	0	0	0	+

Table 4.3 - Interactive matrix of the weakness to opportunities in the project

Weakness of the project				
Project Opportunities		W1	W2	W3
	O1	+	-	+
	O2	-	0	0
	O3	+	-	+
	O4	0	0	0

Table 4.4- Interactive matrix of the weakness to threats in the project

Weakness of the project				
Project Threats		W1	W2	W3
	T1	-	+	+
	T2	+	+	+
	T3	0	-	-
	T4	-	-	-

In the matrix of intersection, there is a definite result: "plus" is a strong match of strength and opportunity, "minus" is a weak ratio. As a result, the final SWOT-analysis matrix was compiled, presented in Table 4.5.

Table 4.5 - SWOT analysis

	Strengths	**Weaknesses**
	S1. The relevance of the selected Topics. S2. The horizontal steam generators with louvre separators helps to	W1. Lack of opportunity to verify all types of PGVs in specific operating modes and also to verify in long term of operation.

	extend the life span of the steam generator. S3. The existence of louvre separator adds to producing high efficiency of dry steam. S4. They provide high operation reliability to the steam generator and the turbine unit as a whole;	W2. The louvre separator adds more weight to the steam generator. W3. Complicated removal of separated water in order not to interfere with the evaporation surface because it can lead to reducing steam volume.
Opportunities O1. creation of new operating modes of PGVs. O2. Support for the development of nuclear energy from the state. O3. Additional demand for research results. O4. Social benefits of nuclear power include direct employment and positive impacts of stable and predictable cost of electricity on the economy.	Analysis results interactive project matrix fields "Strengths and capabilities": 1. Guaranteeing the necessary conditions for conducting experiments. 2. The relevance of the topic helps to secure funding and help to come out with more promising designs	Results of the analysis of the interactive matrix of the field project "Weaknesses and Opportunities": 1. The possibility of financial support from state will allow both troubleshoot verification problem all types of PGVs in any modes of operation, and to solve issue of consideration investigated PGV at more long terms operation. 2. Availability of additional demand for settlement results will also eliminate main drawbacks of the project.
Threats T1. The possibility of damage and subsequent failure the steam installation such as non-uniform boiling and poor steam quality. T2. The likelihood of having similar	Analysis results interactive project matrix fields "Strengths and threats ": 1. The possibility of failure a steam generator will result in an irregularity in the plan pilot research, but	Results of the analysis of the interactive matrix of the field project "Weaknesses and Threats": 1. Conducting similar experiments by competing firms, possibility of damage PGVs, delay in

developments from the competing party. T3. Delivery of project financing. T4. Uncertainties in the construction cost i.e. increase in construction and raw material cost.	support budgetary financing, due to the importance theme of the project, and timely inspection the state of the PGV can reduce the impact of listed threats. 2. Nuclear power generates a lot of income to a country that will cater for all expenses made during construction and the cost of materials.	financing together with the listed weaknesses of the project, are quite strong influence for the execution of the scientific research but listed by us opportunities are proficient to prevent all negative effects.

Thus, by performing a SWOT analysis, it can be concluded that the advantages of the used PGV prevails over its disadvantages. All the existing imperfections can be easily eliminated, taking advantage of the above opportunities.

4.2.4 Evaluation of the project readiness for commercialization

The indicators which depicts the degree of maturity of the project from the perspective of commercialization and competence developer of a research project is considered in the Table 4.6 below.

Table 4. 6 - Blank assess the readiness of a research project to commercialize

S/No	Criteria	Degree of elaboration in the research project	Level of developers existing knowledge
1	Scientific and technical potential is determined	4	4
2	Promising areas of commercialization of scientific and technological potential are identified	4	4
3	Industries and technologies (products and services) to offers on the market are identified	3	3

4	Commodity form (product form) of the scientific and technical basis for the presentation to the market is determined	4	4
5	Author is identified and protection of their rights is secured	3	4
6	Assessment of the value of Intellectual Property is done	4	4
7	Marketing research of potential markets is carried out	3	3
8	Business plan for commercialization of scientific development is developed	3	3
9	The ways of promoting scientific development to the market	5	5
10	The strategy (form) the implementation of scientific development is developed	4	5
11	International cooperation potential and access to foreign markets are studied	3	4
12	Use of infrastructure support services to receive benefits is studied	4	5
13	Funding issues commercialization of scientific development is formed	4	3
14	Team for the commercialization of scientific development is formed	3	3
15	Arrangements for the implementation of a research project are made	4	4
16	Total points (B_{sum})	55	58

Readiness Assessment research project to commercialization (or the level of existing knowledge from the developer) is defined by the formula:

$$B_{sum}=\sum B_i, \quad (4.2)$$

where: B_{sum} - the total number of points in each direction;

B_i - point on the i-th indicator.

The value of B_{sum} suggests the extent of readiness of scientific development and its developer to commercialization. For example, if the value of B_{sum} turned out between 75 and 60, such a development is considered promising, and developer of knowledge sufficient for successful commercialization. If 59 to 45 - that the prospect of above-average. If 44 to 30 - the average prospect. If 29 to 15 - that the prospect of lower than average. If 14 and below - the prospect is extremely low.

The evaluation concludes that the volume of investment in the ongoing development and direction of further development is considered above-average, and developer of knowledge sufficient for successful commercialization.

4.2.5 Methods for the commercialization of scientific and technological research

In the commercialization of scientific and technical developments, the seller (as is usually the owner of the respective intellectual property rights), has a definite purpose, which is largely dependent on where in the future it intends to send (used to invest) resulting commercial effect. The best way of commercialization for this work is by the transfer of know-how which is giving the owner the possibility with the know-how to impact other persons. This is done by exposure of know-how to other persons for more research to be done on it.

4.2.6 Identification of possible alternatives

In order to evaluate the effectiveness of the thesis, we need to develop alternatives of implementation of the project. To do so we can use the morphological approach. Morphological approach is based on a systematic study of all theoretically possible options arising from the structure (morphology) of the research object. Synthesis embraces both known and new unusual variants, which with a simple exhaustive search could be missed. Variants is obtained by combining a large number of different solutions, some of which is of practical interest. This is described by some characteristics which is described in Table 4.7 below.

Table 4.7 - Morphological matrix for research implementation alternatives

Characteristics	Variants					
	1	2	3	4	5	6
Base	University	Research Institute	Production Company			

Executives	Supervisor	Head of Lab	Research Director	Student	Specialist	Engineer
Materials	Free	Bought				
Equipment	Free	Bought	Rented			
Software	General	Special				
Software access	Free	Bought				
Facilities	Office	lab	Classroom			
Facilities access	Free	Bought	Rented			

This stage describes possible solutions of the problem from the perspective of its functional content and resources. For this matrix, yellow represents Alternative 1 which is done in a university. Blue represents Alternative 2 which is performed in a research institute. Green represents Alternative 3 which is performed in production company.

4.3.1 Planning and management of scientific and technical project

Project control events key events of the research project, their dates and results are given in Table 4.8.

Table 4.8 – Project Control Events

No.	Title	Date	Result (confirming document)
1	Selection of research topic	2.02.2018	Supervisor
2	Drafting and approval of the technical assignment.	06.02.2018	Task for the research
3	Practice	29.01.2018	Practice report
4	Searching material and studying literature	6.03.2018	
5	Work scheduling	21.03.2018	Report

6	Acquaintance with features of the work of PGV-1 of Rostov NPP	23.03.2018	Report
7	Formulation of theoretical moisture separation process	15.03.2018	Report
8	Performing calculations and analysis of data received	06.04.2018	Report
9	Attending Conference	16.04.2018	Report
10	Correction of work	25.04.2018	Report
11	Translate foreign materials	11.05.2018	Report
12	Preparation for protection of thesis.	23.05.2018	

4.3.2 Project plan

As part of the planning of the research project, a calendar schedule using the Gantt chart. In this case the Gantt chart was used to map the distribution of the work carried out. Gantt chart is a type of bar charts which is used to illustrate the planned schedule of project, in which the works can be shown the extensive length of time, characterized by the dates of beginning and end of the implementation of these works.

The chart is constructed and shown in table 4.6 below by four-month day working period during run-time of the project. The difference in the length of the distribution of each working period largely depends on the task needed for a particular work. The task performed are written and shown in appendix. The work on the topic is represented by long stretches of time, characterized by the dates of commencement and completion of work in Table 4.9.

Table 4.9 – Shows the project schedule

work code (of the WBS)	Title	Duration, days	Date of start	Date of completion	Participants (name of responsible persons)
1	Selection of research topic	3	2.02.2018	05.02.2018	Supervisor
2	Drafting and approval of the technical assignment.	3	06.02.2018	09.02.2018	Supervisor Engineer
3	Practice	35	29.01.2018	4.03.2018	engineer
4	Searching material and studying literature	76	7.02.2018	24.04.2018	engineer
5	Work scheduling	3	21.03.2018	23.03.2018	Engineer
6	Acquaintance with features of the work of PGV-1 of Rostov NPP	5	23.03.2018	28.03.2018	Engineer
7	Formulation of theoretical moisture separation process	20	15.03.2018	05.04.2018	Engineer Supervisor
8	Performing calculations and analysis of data received	7	06.04.2018	13.04.2018	Engineer
9	Attending Conference	5	16.04.2018	20.04.2018	Engineer
10	Correction of thesis work	11	25.04.2018	10.05.2018	Engineer Supervisor
11	Translate foreign materials	10	11.05.2018	20.05.2018	Engineer
12	Preparation for protection of thesis work	29	23.05.2018	30.05.2018	Engineer

Table 4.10 – Presents the schedule scientific research

Code of work (from ИСР)	Type of work	Performer	Tк, cal, days.	Duration of work														
				Feb			March			April			May			June		
				1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
1	Selection of research topic	Supervisor	3															
2	Drafting and approval of the technical assignment.	Supervisor Engineer	3															
3	Practice	Engineer	35															
4	Searching material and studying literature	Engineer	76															
5	Work scheduling	Engineer	3															
6	Acquaintance with features of the work of PGV-1 of Rostov NPP	Engineer	5															
7	Formulation of theoretical moisture separation process	Engineer Supervisor	20															
8	Performing calculations and analysis of data received	Engineer	7															
9	Attending Conference	Engineer	5															
10	Correction of work	Engineer Supervisor	11															

11	Translate foreign materials	Engineer	10															
12	Preparation for protection of thesis work.	Engineer	29															

\- Supervisor - Student

4.4 Budget of scientific research

When planning the research budget, it must be ensured that full and reliable reflection of all types of costs associated with its implementation. In the process of budget formation, cost like material costs, costs for special equipment for scientific work, additional salaries among others were calculated.

The scientific work was carried out under a budget allocated to a supervisor and one student of the university. The supervisor is allocated 300 Rub per hour and the engineer has 100 Rub per hour. The main costs in this research are costs for electricity and purchase of office supplies. The cost of electricity is calculated by the formula:

$$C = T_{el} \cdot P \cdot t = 6 \cdot 0.5 \cdot 480 = 1440,$$

where, T_{el} - tariff for industrial electricity (6 rubles per 1 kW · h);

P - capacity of equipment, kW;

t - time of use of equipment, h (120×4).

4.4.1 Raw materials, purchased products and semi-finished products

This item includes the cost of all kinds of purchasing materials, components and semi-finished products necessary for the implementation of works on the subject. Number of required material values determined by the norms of consumption. Material cost calculation is carried out according to the following formula:

$$C_m = (1 + K_{tr}) \cdot \sum_{i=1}^{m} p_i \cdot N_i, \qquad (4.3)$$

where, m – number of types of material resources consumed in carrying out scientific research;

Ni – the number of physical resources i-th species, planned to be used in carrying out scientific research (pieces, kg, m, mon.);2 and so

Pi – acquisition unit price i-th species consumable material resources (rubles / pc, rub / kg, rub / m, rub / m etc.....);

ktr – coefficient taking into account transportation and procurement costs.

Calculating the expenses of material costs based on the current price list or negotiated prices. The expenses of material costs include transportation and procurement costs (15-25% of the price). In the same item, includes the expenses of paperwork (stationery, copying materials). The results of this term are presented in the Table 4.11 below.

Table 4.11 – Raw materials, components and semi-finished products

Title	unit	Quantity			Price per each, ruble			The sum, ruble		
		Atl 1	Alt 2	Alt 3	Atl 1	Alt 2	Alt 3	Atl 1	Alt 2	Alt 3
Electricity	-	480 kW°hr	500 kW°hr	520 kW°hr	6	6	6	1440	3000	3120
Paper	SvetoCopy	1 packet of 500 sheets	1 packet of 500 sheets	1 packet of 500 sheets	0.54	0.54	0.54	270	270	270
Printing	-	500	520	530	2	2	2	1000	1040	1060
Pen	Stabilo	4	4	4	30	30	30	120	120	120
Access to the Internet	-	4 months	4 months	4 months	350	350	350	1400	1400	1400
Total of materials								4230	5830	5970
Transportation and procurement expenses (15%)								634.5	874.5	895.5
Total items $C_М$								**4864.5**	**6704.5**	**6865.5**

4.4.2 Calculation of costs for special equipment for scientific (experimental works)

This item includes all costs associated with the acquisition special equipment necessary for work on specific topic. In this research work on special equipment, necessary for carrying out experimental work is a personal computer which costs 30,000 rubles, with a life service of 4 years.

Table 4.12 Calculation of the budget cost for the purchase of special equipment for scientific paper

#	Name of equipment	Number of units of equipment			unit price of equipment, ths. Rub.			The total cost of equipment, ths. Rub.		
		Atl 1	Alt 2	Alt 3	Atl 1	Alt 2	Alt 3	Atl 1	Alt 2	Alt 3
1	computer	1	1	1	30000	40000	42000	30000	40000	42000
Total:								30000	40000	42000

4.4.3 The basic salary of the performers of the topic

The article includes the basic wages of employees, directly involved in the implementation of the project (including bonuses, co-payments) and additional wages.

The item includes basic wages of workers directly involved in the implementation of the project (including premiums, bonuses) and additional wages.

Table 4.13 – Calculation of basic salary

#	Executives	Work, person-days.			Salaries per one person-days, ths. Rub.			Total salaries at the rate (salary), ths. Rub.		
		Atl 1	Alt 2	Alt 3	Atl 1	Alt 2	Alt 3	Atl 1	Alt 2	Alt 3
1	supervisor	30	-	-	3680	-	-	110400	-	-

2	Head of Lab	-	40	-	-	4140	-	-	165600	-
3	Research Director	-	-	45	-	-	4600	-	-	207000
4	student	120	-	-	896	-	-	107520	-	
5	Specialist	-	60	-	-	2688	-	-	161280	-
6	Engineer	-	-	60	-	-	2688	-	-	161280
Total								**217920**	**326880**	**368280**

4.4.4 The main salary of the performers of the topic

The article includes the basic wages of employees, directly involved in the implementation of the project (including bonuses, co-payments) and additional wages. The item includes basic wages of workers directly involved in the implementation of the project (including premiums, bonuses) and additional wages.

$$S_t = S_b + S_{ad} \quad (4.4)$$

where S_b – basic salary;

S_{ad} – additional salary.

Basic salary can be calculated, based on hourly labor rates:

$$S_b = S_h * 8 \quad (4.5)$$

where S_h - basic salary of one employee per hour, rub/hour; Hourly labor rate may vary depending on the type of executive in the research project.

Additional salary of performers of the topic

Costs for additional pay for the performers of the topic allowance for the amount of additional payments foreseen in the Labor Code of the Russian Federation for deviation from normal working conditions, as well as payments related to guarantees and compensation. Calculation additional salary conducted according to the following formula:

$$S_{ad} = k_{ad} * S_b \quad (4.6)$$

where k_{ad} - factor of additional salary (taken at the design stage at 0.12 - 0.15).

We take the coefficient of additional salary equal to 0.15 for the supervisors while 0.12 for an engineer, student and specialist. The results of calculating the main and additional salaries of performers of scientific research are presented in Table 4.13.

4.4.5. Contributions to social funds (insurance contributions)

In Russian Federation, employees pay insurance payments for state social insurance fund (SIF), the Pension Fund (PF) and medical insurance fund (MIF). Employers on behalf of the employees make these payments. Contributions to these funds determined based on the following formula:

$$S_f = k_f * (S_b + S_{ad}) \quad (4.7)$$

where k_f - coefficient for payments to funds (SIF, PF, MIF).

In 2018 the size of insurance payments was set at the level of 30%. Yet for institutions engaged in educational and scientific activity the reduced rate of 27.1% is used. Social funds contributions have been calculated and tabulated in Table 4.14

Table 4.14 Illustrates contributions to social funds

Artist	basic salary, rubles.			Additional salary, rubles.		
	Alt.1	Alt.2	Alt.3	Alt.1	Alt.2	Alt.3
Supervisor	3200			480		
Head of Lab		3600			540	
Research Director			4000			600
Student	800			96		
Specialist		2400			288	
Engineer			2400			288
Ratio of contributions to social funds	27.1%	27.1%	30%	27.1%	27.1%	30%
Total amount of social fund payments						
Alternative 1	1240.10					
Alternative 2	1850.39					

Alternative 3	2186.40

4.4.6 Overhead costs

This article includes the costs of management and maintenance, which can be attributed directly to a particular topic. In addition, this includes expenses for the maintenance, operation and repair of equipment, production tools and equipment, buildings, structures, etc. The calculation of overhead costs is carried out according to the following formula:

$$C_{ovh} = C_{total} * k_{ovh} \quad (4.8)$$

Where, C_{total} – Total costs of the above cost items in 1 – 7

k_{ovh} – Overhead coefficient, which can be taken at a rate of 16%.

Table 4.15 Illustrates the overhead cost made in the project

	Alt 1	Alt 2	Alt 3
C_{total}	254024	375434	419331
C_{ovh}	40643	60069	67093

The calculated value of the costs of research work is the basis for the formation of the project cost budget, which, when forming an agreement with the customer, is protected by a scientific organization as the lower limit of the cost of developing scientific and technical products. The definition of the cost budget for a research project for each option is shown in Table 4.16.

Table 4.16 – Calculation of the expenditure budget of the research project

S.No	Name of the item	Amount, Rubles		
		Alt 1	Alt 2	Alt 3
1	Material costs of the study	4865	6705	6866
2	Expenses for special equipment	30000	40000	42000

3	Costs for the salaries of the performers of the topic	217920	326880	368280
4	Contributions to social funds	1240	1850	2186
5	Overhead expenses	40644	60070	67093
6	Research Cost Budget	**294669**	**435504**	**486425**

4.5 The definition of resource (resource-saving), financial, budgetary, social and economic research effectiveness

The definition of efficiency is based on the calculation integral indicator of the effectiveness of the scientific research and this can be related to the definition of two weighted averages; financial efficiency and resource efficiency. Integral financial efficiency indicator development is defined as:

$$E_{\text{fin}}^{\text{alt.i}} = \frac{TC_i}{TC_{max}} \quad (4.9)$$

where $E_{\text{fin}}^{\text{alt.i}}$ – an integral index of financial efficiency;

TC_i – Total cost of the i-th alternative;

TC_{max} – the maximum total cost of research project (including analogs).

The obtained value of the integral financial indicator of the development reflects the corresponding numerical increase in the development costs budget in times (value greater than one), or the corresponding numerical reduction in the cost of development in times (the value is less than one, but greater than zero). Since the development has one execution, then;

$$E_{\text{fin}}^{\text{alt.1}} = \frac{TC_1}{TC_{max}} = \frac{294668.54}{486425.00} = 0.61,$$

$$E_{\text{fin}}^{\text{alt.2}} = \frac{TC_{alt.2}}{TC_{max}} = \frac{435504.47}{486425.00} = 0.90,$$

$$E_{\text{fin}}^{\text{alt.3}} = \frac{TC_{alt.3}}{TC_{max}} = \frac{486425.00}{486425.00} = 1.$$

Integral resource-efficiency indicator of research alternatives can be determined as follows:

$$E_{\mathrm{res}}^{\mathrm{alt.i}} = \sum a_i \cdot b_i, \qquad (4.10)$$

where, $E_{\mathrm{res}}^{\mathrm{alt.i}}$– an integral indicator resource for i-th embodiment of the development;

a_i – weight factor of i-th research alternative;

b_i – a score of i-th execution of development options is set by an expert in the chosen scale of assessment;

n – number of parameters comparison. Calculation of the integral indicator resource is recommended in tabular form (Table 4.17).

Table 4.17: Comparative evaluation of characteristics of the project alternatives

Criteria	a_i Weight	b_i score		
		Alt.1	Alt.2	Alt.3
1. Promotes growth user productivity	0.25	3	3	4
2. Ease of operation (corresponding to the requirements of consumers)	0.2	3	4	4
3. Interferences	0.05	3	3	3
4. Energy savings	0.2	2	3	3
5. Reliability	0.15	3	4	4
6. Material	0,15	4	4	3
TOTAL	1	18	21	21

Alt.1 = 3·0.25 + 3·0.2 + 3·0.05 + 2·0.2 + 3·0.15 + 4·0.15 = 2.95;

Alt.2 = 3·0.25 + 4·0.2 + 3·0.05 + 3·0.2 + 4·0.15 + 4·0.15 = 3.50;

Alt.3 = 4·0.25 + 4·0.2 + 3·0.05 + 3·0.2 + 4·0.15 + 3·0.15 = 3.60.

Integral total efficiency indicator of alternatives is determined based on the integral resource and financial efficiency by formula

$$E_{\mathrm{total}}^{\mathrm{alt.i}} = \frac{E_{res}^{\mathrm{alt.i}}}{E_{\mathrm{fin}}^{\mathrm{alt.i}}} \qquad (4.11)$$

Therefore,

$$E_{\mathrm{total}}^{\mathrm{alt.1}} = \frac{E_{res}^{\mathrm{alt.1}}}{E_{\mathrm{fin}}^{\mathrm{alt.1}}} = \frac{2.95}{0.61} = 4.8;\ E_{\mathrm{total}}^{\mathrm{alt.2}} = \frac{E_{res}^{\mathrm{alt.2}}}{E_{\mathrm{fin}}^{\mathrm{alt.2}}} = \frac{3.5}{0.9} = 3.9;\ E_{\mathrm{total}}^{\mathrm{alt.3}} = \frac{E_{res}^{\mathrm{alt.3}}}{E_{\mathrm{fin}}^{\mathrm{alt.3}}} = \frac{3.6}{1} = 3.6$$

Comparison of the integrated indicator of the effectiveness of the current project and its analogues will determine the comparative effectiveness of the project. Comparative efficiency of the project:

$$E_{\text{comp}}^{\text{alt.i}} = \frac{E_{total}^{\text{alt.i}}}{E_{\text{total}}^{\text{min}}} \qquad (4.12)$$

The result of calculating the comparative efficiency of the project and the comparative effectiveness of the analysis are presented in Table 4.18.

Table 4.18 Comparative development effectiveness

№ p / p	Indicators	Alt.1	Alt.2	Alt.3
1	Integral financial efficiency indicator	0.61	0.90	1.00
2	Integral resource-efficiency indicator	2.95	3.50	4.50
3	Integral total efficiency indicator	4.80	3.90	3.60
4	Comparative project efficiency indicator	1.33	1.08	1.00

Therefore, based on the definition of resource-saving, financial, budgetary, social and economic efficiency of the research, having carried out the necessary comparative analysis, it can be seen that the development made by a university is cost effective and the efficiency is 1.33 times higher than the development made in a production company. This can therefore be concluded that, it was good to do such a research in a university.